J R C T E C H N I C A L R E P O R T S

The a4a Assessment Model

Model description and testing

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Abstract

The a4a initiative aims to provide timely and cost effective advice for the circa. 250 fish stocks that, through the EU Data Collection Framework, will have at least 10 years of data by the year 2020. Current processes for assessing the state of and managing fish stocks are intensive processes, each stock requiring the attention of one or more stock assessment scientist to produce preliminary catch advice, which is subsequently reviewed by one or two committees before the final catch advice is published. Ingrained in the development of these processes has been the development of more and more complex stock assessment models which typically require highly skilled personnel to set up and run.

The a4a initiative seeks to overcome these issues by developing a flexible, robust and easy to use stock assessment model, thus making stock assessment accessible to a wide range of scientists that do not have the high skilled quantitative background required to run very complex models. Forthcoming research will describe how to overcome the burden of producing catch advice for such a large number of stocks. This technical report presents a new stock assessment model along with a set of validatory tests developed under the a4a Initiative.

Introduction

The a4a Initiative is a visionary reseach initiative aiming to provide method to use the increasing amounts of data on fish stocks being collected under the Data Collection Framework (DCF). The implementation of the 2009 revision of the DCF [1] generated the obligation to collect a large amount of information for all stocks being subject to fisheries exploitation. Based on the regulation there are 250+ stocks for which some kind of biological information must be collected. Most of these stocks will have in thefuture, ∼2020, time series of exploitation data more than 10 years long, although the biological information will most likely be limited due to the high human resources requirements to process all the samples collected. These stocks (will) have a moderate amount of information and won't fit into the data poor stock definition. In addition, due to the large number of these stocks, it is not logistically feasible to run on all of them complex data eager models that require a high level of expertise. What is required is a robust methodology that allows the assessments of a large number of stocks by stock assessment experts with distinct backgrounds.

Estimating demographics and exploitation rates of fish stocks is the basis of current management advice across most of the world. Assessing the state of stocks has been developing over the last 50 to 100 years, and during this period many models have evolved and there are around 40 stock assessment methods in use today (SCISAM report). Some examples of age based methods in current use are XSA (Shepherd, 1992), ASM (NOAA Fisheries Toolbox), TSA (Fryer 1999, Gudmundson 1990) and SAM (Neilsen, 2008) and all are based on similar underlying assumptions regarding stock dynamics. The main differences between these methods is in how they consider the data and how the fishery dynamics are modelled, and of course the user interface. This report presents a framework which allows the construction of models that mimic many of the currently available age based stock assessment methods in a statistical setting, while also making available current statistical modelling techniques such as additive models (Wood, 2006) and structured random effects (Rue and Held, 2005).

The model is a simple statistical catch at age model in which the population dynamics are simply that the numbers of fish in a cohort declines from year to year due to a combination of natural mortality and fishing mortality. We in effect observe the population through the catches removed by the fishery and more directly through a survey conducted at some point in the year. Where the complexity and diversity in stock assessment models arise is usually in how fishing mortality is modelled. Because it is not possible to estimate everything (the model parameters would be unidentifiable) it is nessisary to constrain it, and this can be done in many ways. Here, we propose the use of splines and random effects to provide a robust and efficient way to constrain the model, and this is packaged in a robust and user freindly statistical framework.

The Report begins with a breif technical description of the model with two examples to demonstrate the application of the model to the North Sea plaice data set. Extensions are breifly discussed. The second half of the report is a presentation of extensive model testing and validation on simulated data sets. The simulation procedure is described and the data sets presented. Finally the model is fitted to each data set and a selection of fits are shown.

[1] Data Collection Framework (2008/949/EC)

Model Description

The basis of the model is

$$N_{a+1,t+1} = N_{at} e^{-(F_{at}+M_{at})}$$

predicted **catches** are

$$\hat{C}_{at} = \frac{F_{at}}{F_{at}+M_{at}} \left(1 - e^{-(F_{at}+M_{at})}\right) N_{at}$$

and predicted survey **indices** are

$$\hat{I}_{at} = Q_a N_{at} e^{-\delta(F_{at}+M_{at})}$$

So the predictions are completely determined by:

$$\begin{array}{ll} R_t = N_{1,t} & \text{i.e. recruitment} \\ A_a = N_{a,1} & \text{i.e. initial age structure} \\ F_{at} & \text{i.e. Fishing mortality} \\ Q_a & \text{i.e. catchability at age} \end{array}$$

and we observe these through

$$\log I_{at} \sim N\left(\log \hat{I}_{at}, \quad \sigma_a\right)$$

$$\log C_{at} \sim N\left(\log \hat{C}_{at}, \quad \tau_a\right)$$

We parameterise the model using linear models.

$$\text{i.e.} \quad \log F_{at} \sim \text{factor}(age) + \text{factor}(year)$$

or

$$\log F_{at} \sim \text{s}(age) + \text{factor}(year)$$

These are examples of seperable F assumptions
The function s(.) is a smooth function (stolen from the mgcv package in R)

A simple example: seperable F

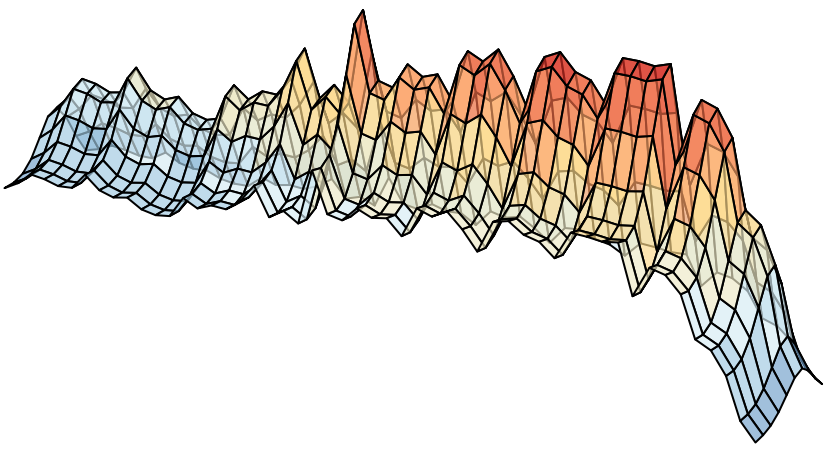

Figure 1: A simple example: seperable F

$$\log F_{at} \sim \mathrm{s}(age, 4) + \mathrm{factor}(year)$$
$$\log Q_a \sim \mathrm{s}(age, 4)$$

A more complex example: Changing F pattern

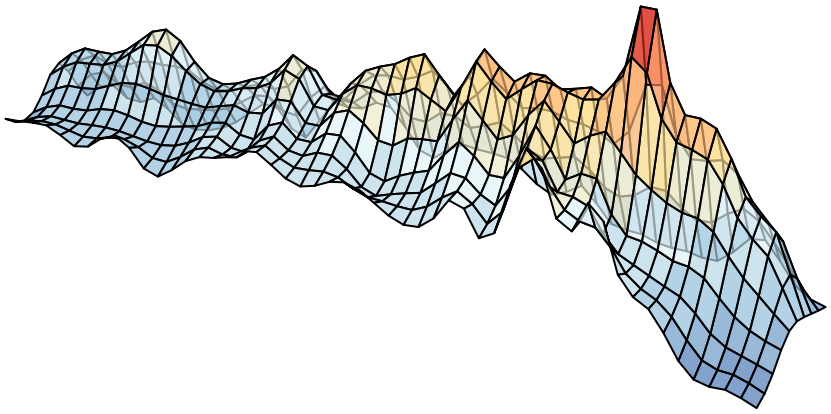

Figure 2: A more complex example: Changing F pattern

$$\log F_{at} \sim \mathrm{s}(age, year, (4, 30))$$
$$\log Q_a \sim \mathrm{s}(age, 4)$$

Extensions

We can introduce covariates through the formulas. Include tecnological creep in surveys. Add temperature data to recruitment. Model spikes in recruitment in terms of environmental covariates. we can allow changes in survey selectivity. by using 2d smooths - useful perhaps for North Sea plaice surveys

However, The model has the potential to be very complex: random effects (fixed variance) around log F, log Q, log R; All the complaints people have with gams exist here. But,we can package it to reduce the options available:

- stable fishery (seperable F)
- Changing fishery (F pattern can evolve)
- Impose exponential survey selectivity
- impose flat top selection

Model Tests

Here follows the simulation testing design:

1. Tests run on WKLIFE simulated stocks.
2. Stocks in 5 different exploitation status used:
    - developing
    - developing and stabilizing
    - stable at high exploitation
    - recovery

- full developing-stable-recovery

3. Data series 15 years long, except "full" with 50 years.
4. Survey index with decreasing catchability, bottom trawl type, with 10% cv. Note that the survey index becomes very informative with abundance between all ages correlated.
5. Catch-at-age with 10% cv observation error.

Inputs

Developing

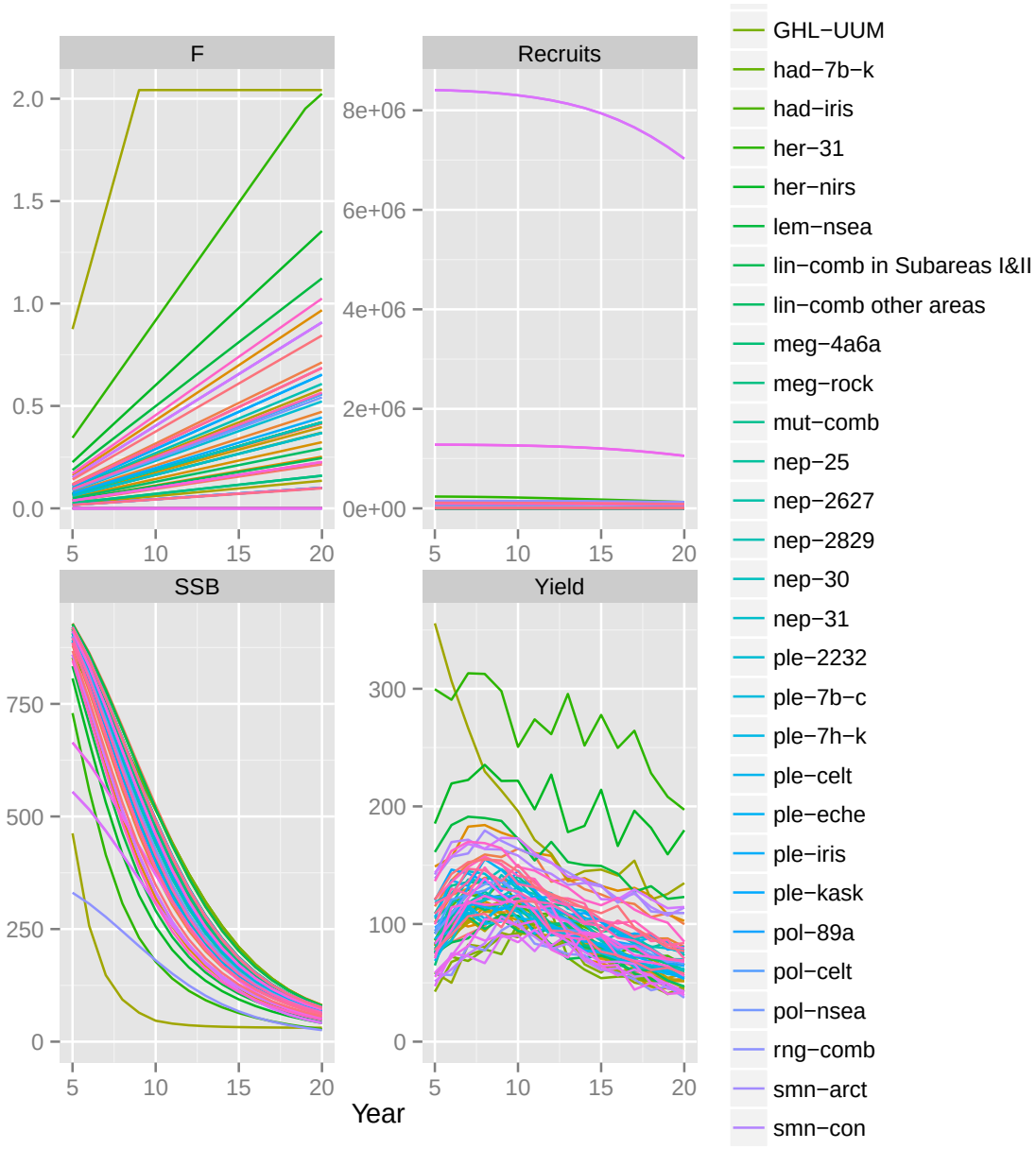

Figure 3: Developing fishery. Stocks based on WKLIFE life history parameters list.

Developing and stabilizing

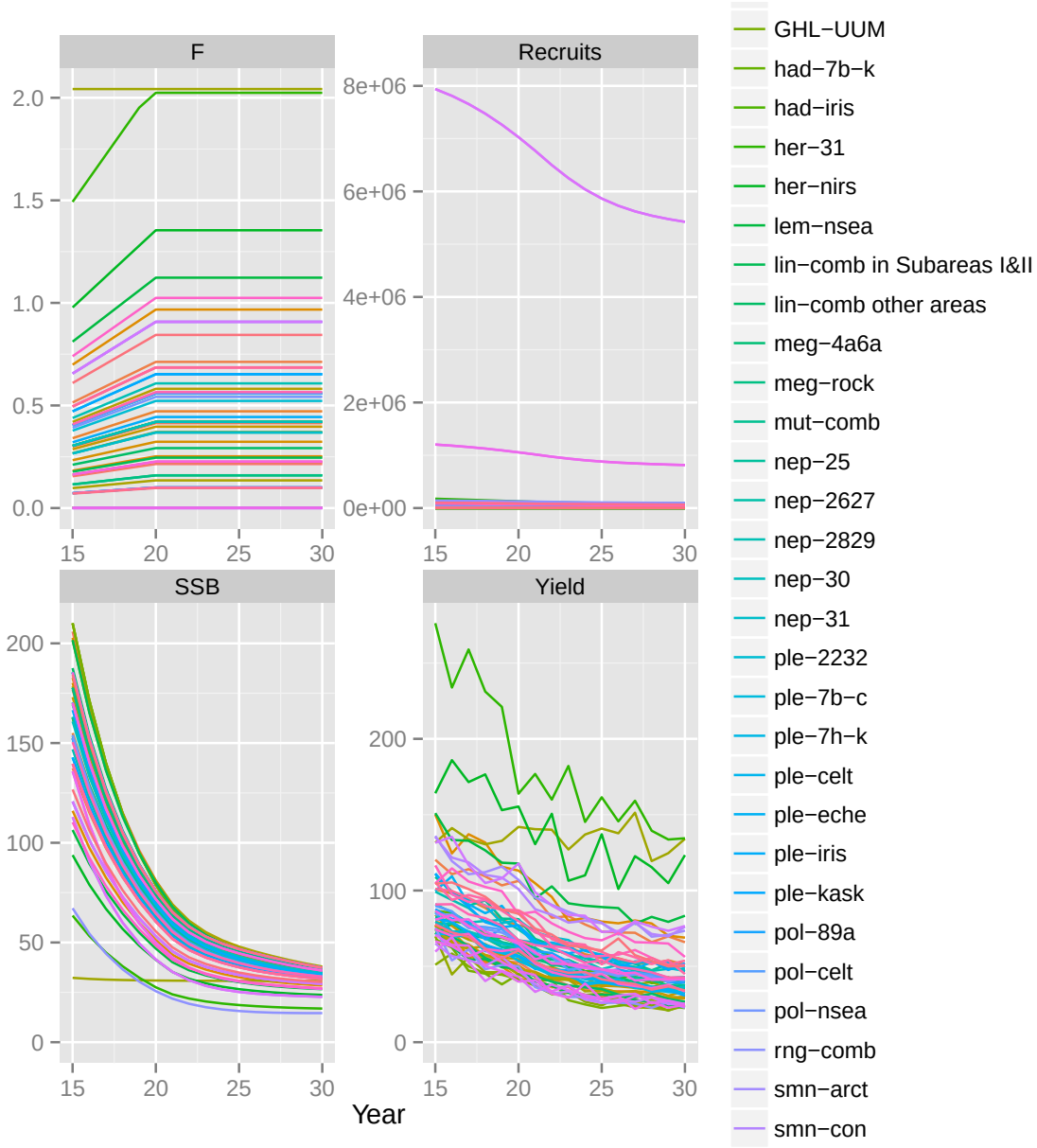

Figure 4: Developing and stabilizing fishery. Stocks based on WKLIFE life history parameters list.

Stable at high exploitation

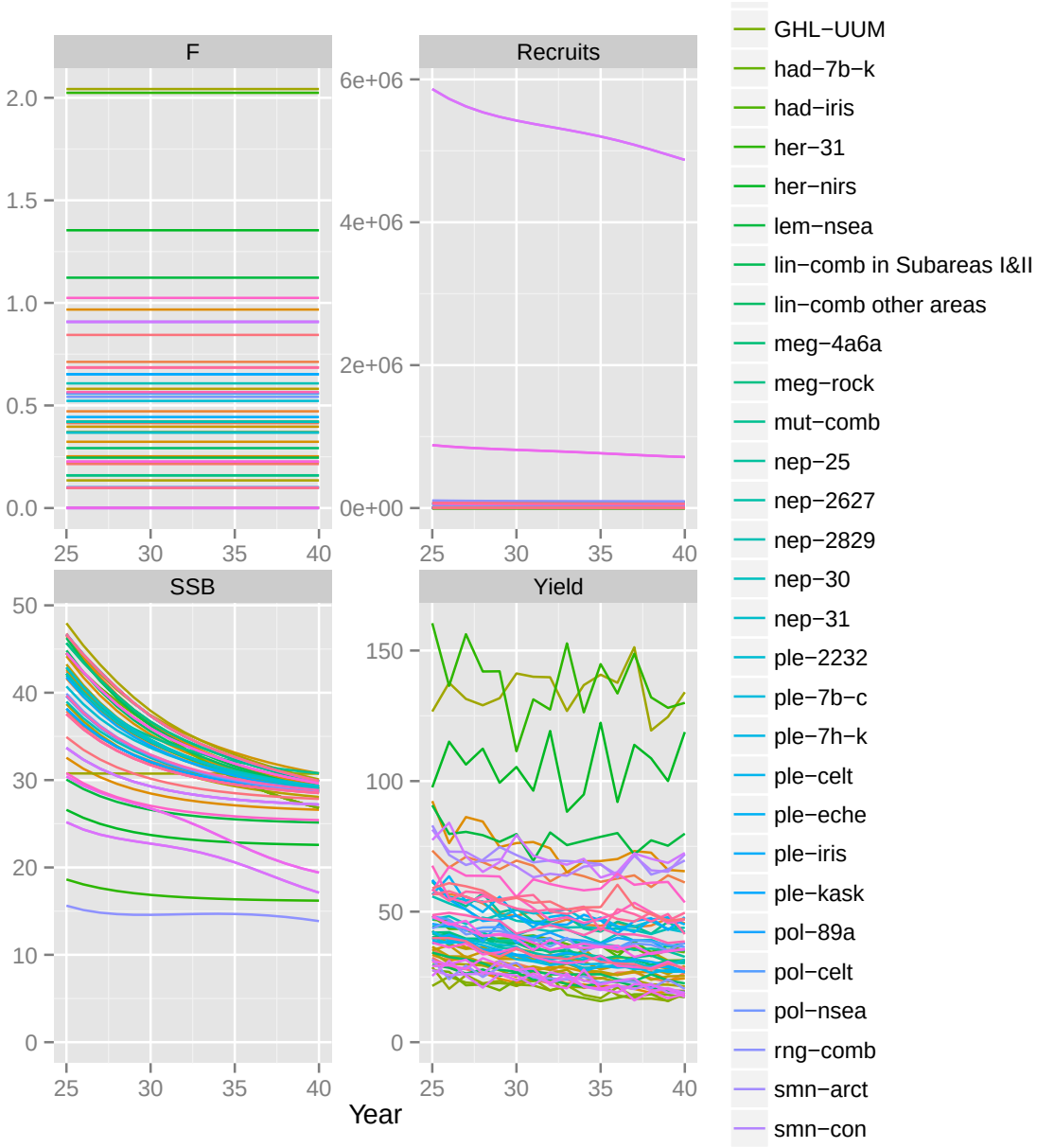

Figure 5: Stable at high exploitation fishery. Stocks based on WKLIFE life history parameters list.

Recovery

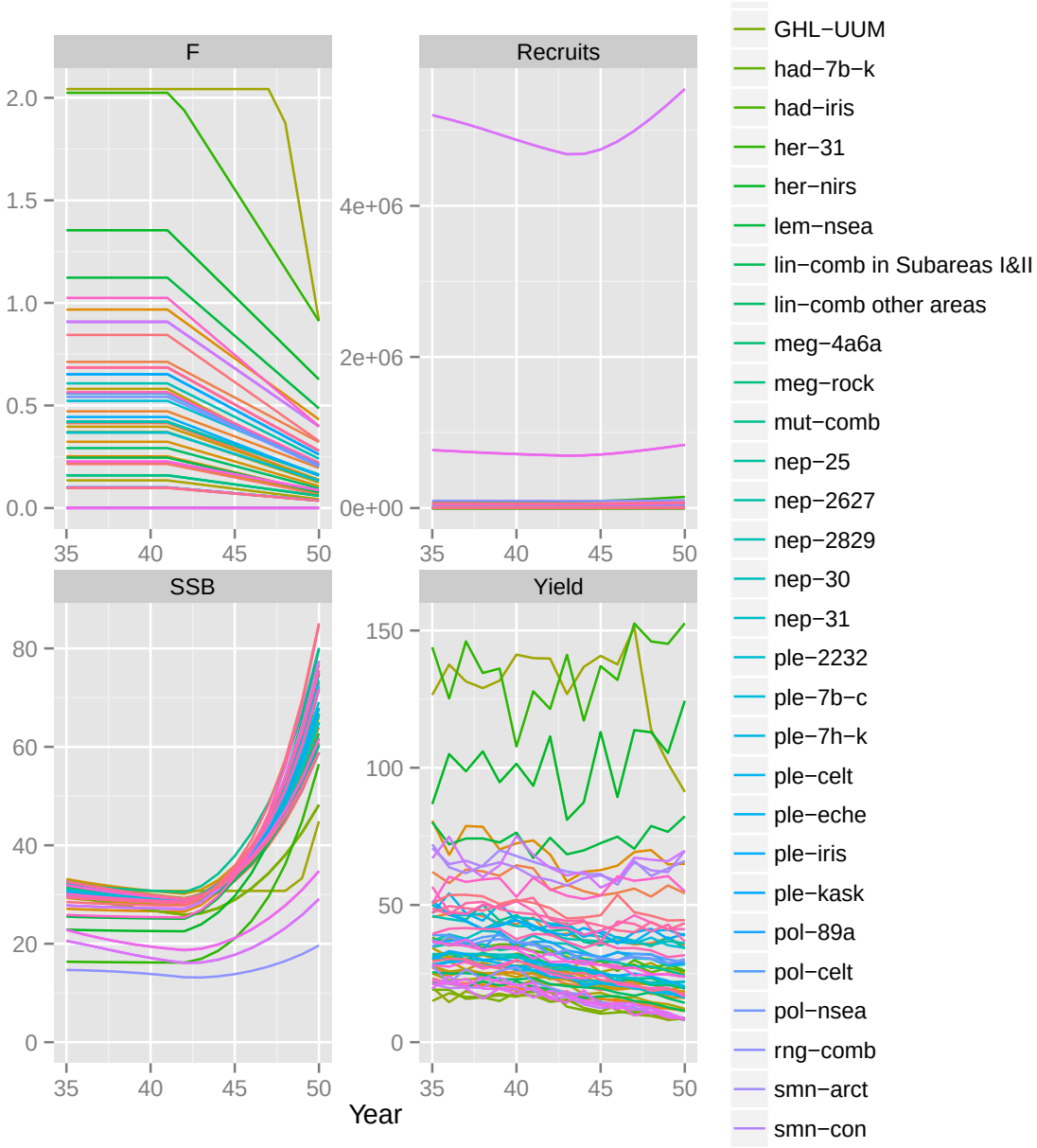

Figure 6: Recovery fishery. Stocks based on WKLIFE life history parameters list.

Full developing-stable-recovery

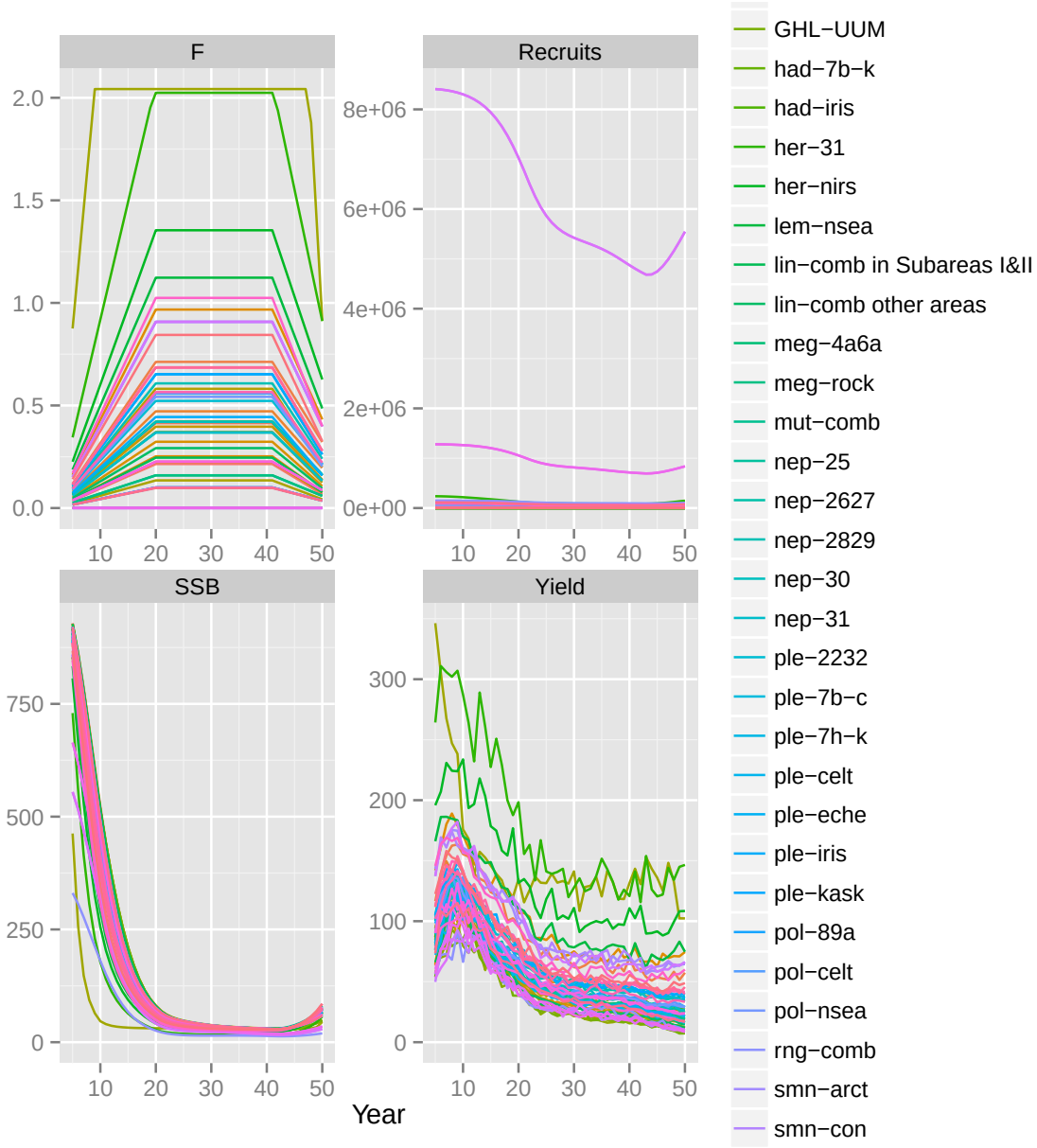

Figure 7: Full developing-stable-recovery fishery. Stocks based on WKLIFE life history parameters list.

Generating survey index and adding observation error to catches

```
set.seed(239246)
stks01 <- mclapply(stks01, genObs)
```

```
genObs

## function(x) {
##   stock <- x $ stock
##  ages <- 1:min(9, range(stock)["max"])
##  range(stock)[c("minfbar","maxfbar")] <- c(2, min(5, max(ages)))
##  stock <- setPlusGroup(stock, max(ages))
##   n <- stock.n(stock)
##   z <- harvest(stock) + m(stock)
##   logq <- -exp(-exp(0.2 * ages)) - 3 # trawl like catchability
```

```
##   # observe index in 1st quarter with 10% cv
##   index <- FLIndex(index = n * exp(-0.25 * z) * exp(logq + rnorm(prod(dim(n)), 0, .1)))  # 10% cv
##   range(index)[c("startf","endf")] <- 0.25
##   # observe catch with 10% cv
##   catch.n(stock) <- catch.n(stock) * exp(rnorm(prod(dim(n)), 0, .1)) # 10% cv
##   catch(stock) <- computeCatch( stock )
##   list(stock = stock, index = list(index))
## }
```

```
stks02 <- mclapply(stks02, genObs)
#
stks03 <- mclapply(stks03, genObs)
#
stks04 <- mclapply(stks04, genObs)
#
stks05 <- mclapply(stks05, genObs)
```

Model fit

The model chosen for simulation testing has an evolving F pattern in which the F-at-age patter has 4 degrees of freedom and evovles over time with 10 degrees of freedom.

```
fmodel <- ~te(age, year, k = c(4, 10))
qmodel <- list(~factor(age))
```

```
fits01 <- mclapply(stks01, doFits, fmodel = fmodel, qmodel = qmodel)
```

here the fitting function has been placed in a wrapper function to catch errors. Normally the user would fit the model using a single call to `a4aFit`

```
doFits

## function(x, fmodel, qmodel, rmodel = ~ factor(year)) {
##   msg <- paste0("fitting ", x$stock@name, " in PID: ", Sys.getpid(), "\n")
##   cat(msg)
##   fit <- try( a4aFit(fmodel, qmodel, rmodel, x$stock, x$index) )
##   if (is(fit, "try-error")) {
##     fit
##   } else {
##     list(sim = x$stock, fit = fit)
##   }
## }
```

```
fits02 <- mclapply(stks02, doFits, fmodel = fmodel, qmodel = qmodel)
```

```
fits03 <- mclapply(stks03, doFits, fmodel = fmodel, qmodel = qmodel)
```

```
fits04 <- mclapply(stks04, doFits, fmodel = fmodel, qmodel = qmodel)
```

```
fits05 <- mclapply(stks05, doFits, fmodel = fmodel, qmodel = qmodel)
```

Model diagnostics

Developing

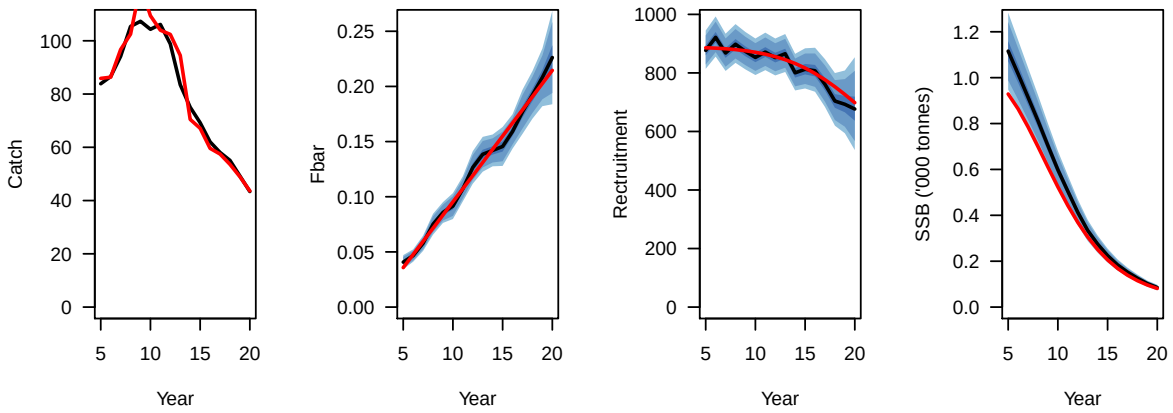

Figure 8: Model residuals. Colours represent ages

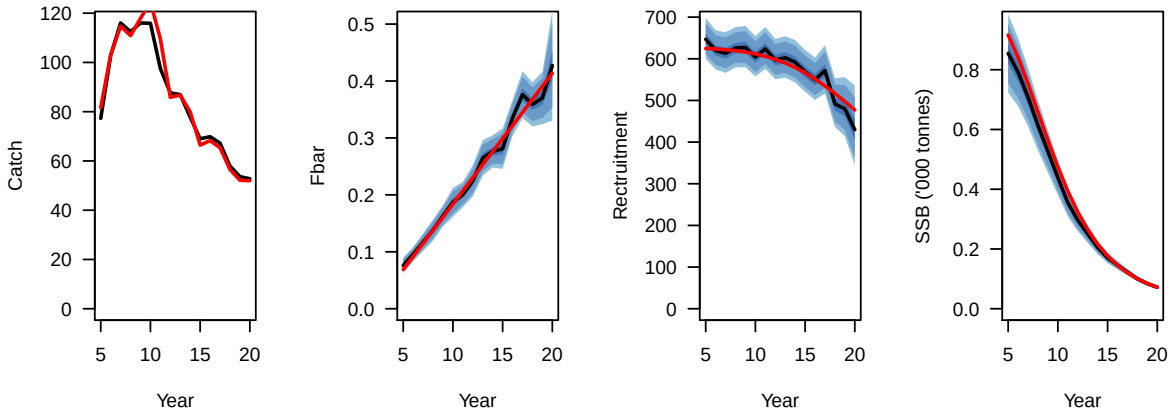

Figure 9: Model residuals. Colours represent ages

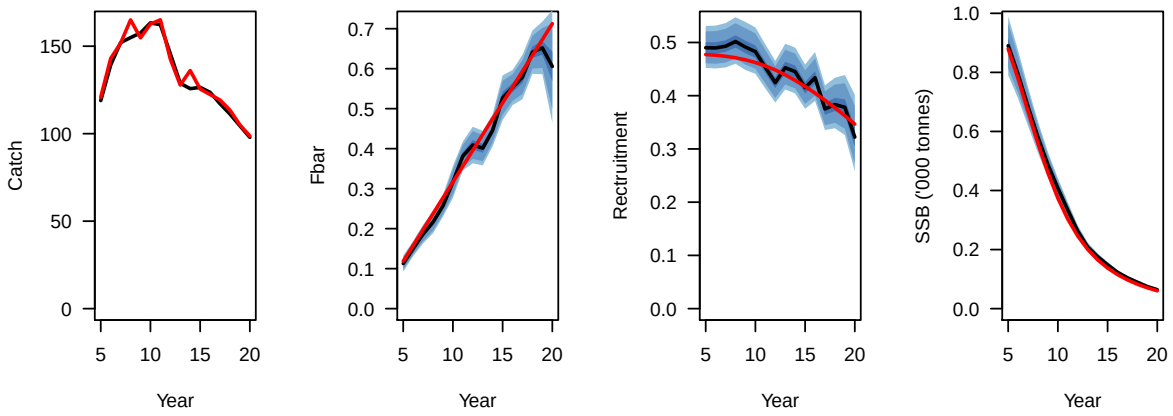

Figure 10: Model residuals. Colours represent ages

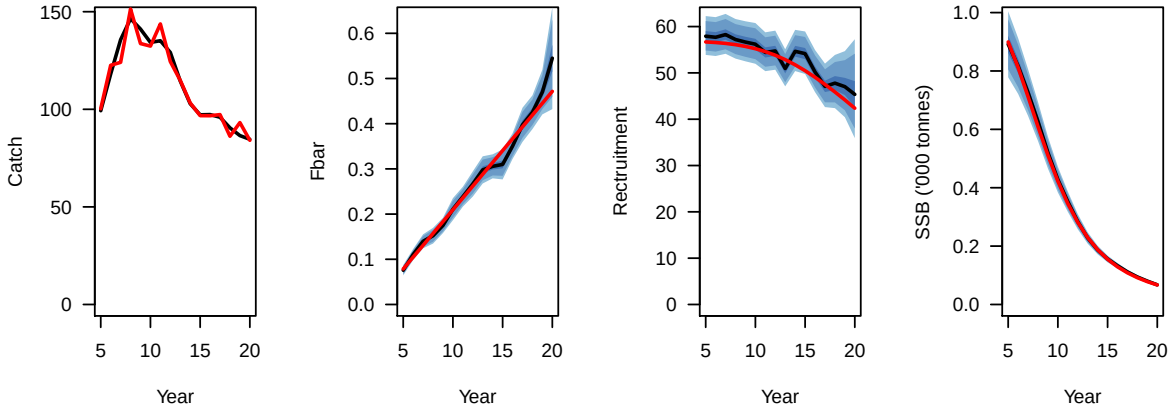

Figure 11: Model residuals. Colours represent ages

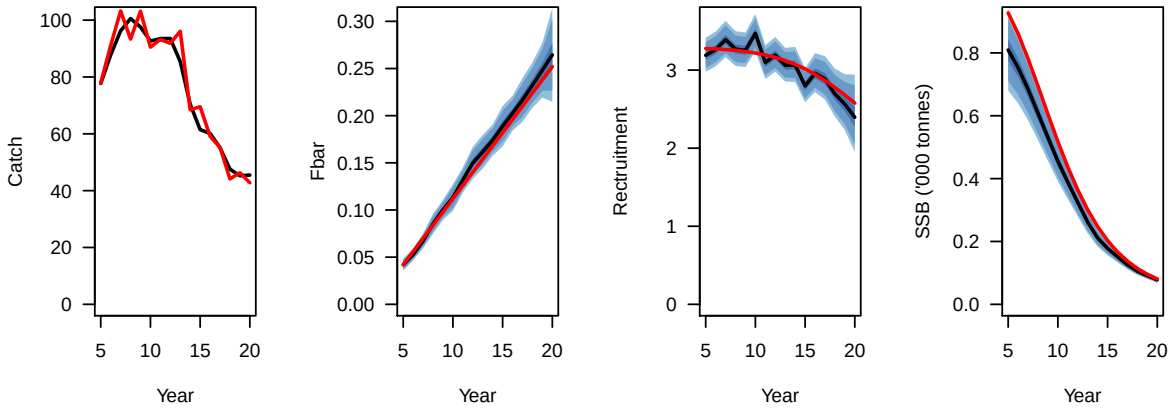

Figure 12: Model residuals. Colours represent ages

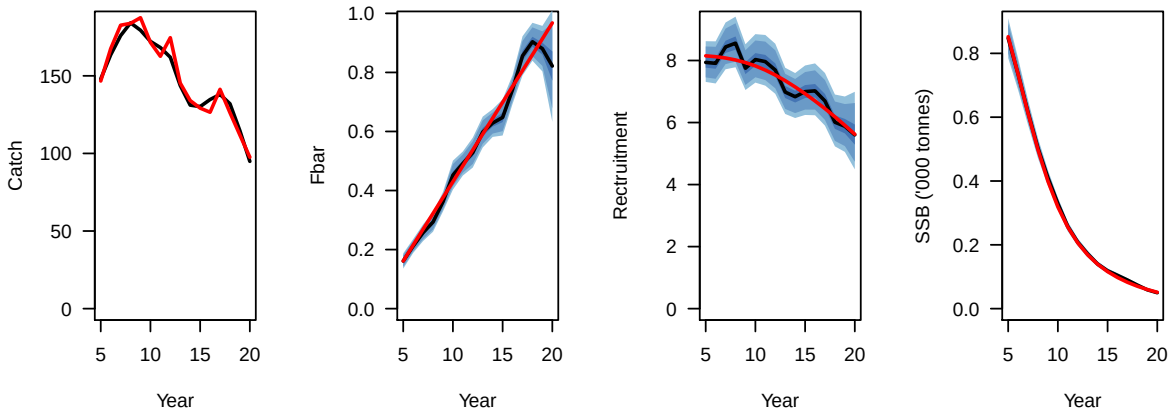

Figure 13: Model residuals. Colours represent ages

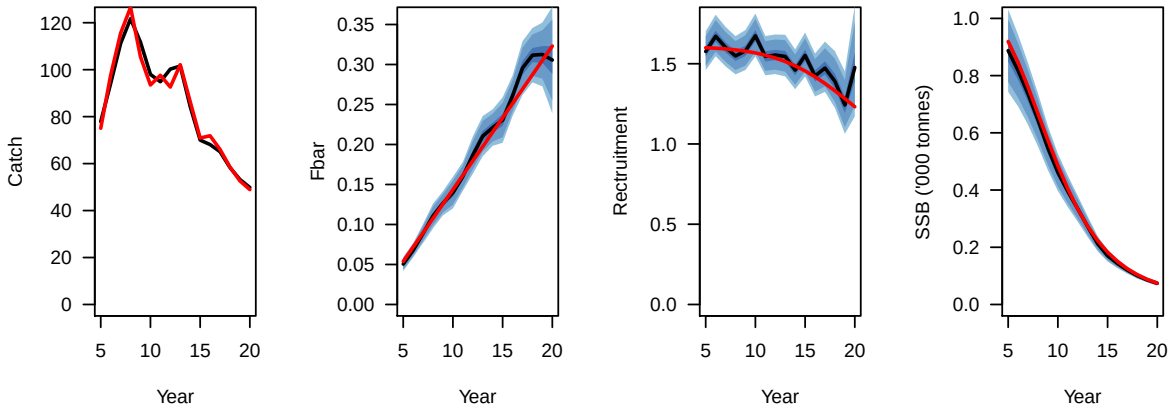

Figure 14: Model residuals. Colours represent ages

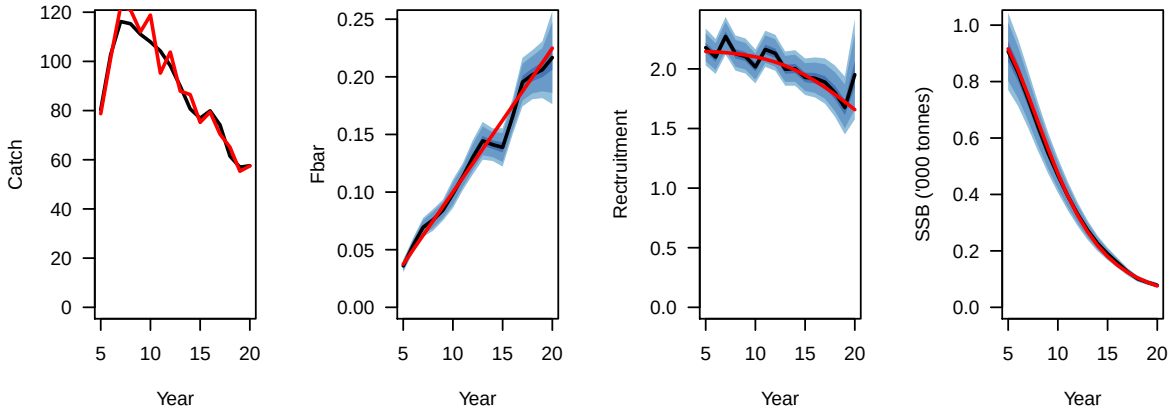

Figure 15: Model residuals. Colours represent ages

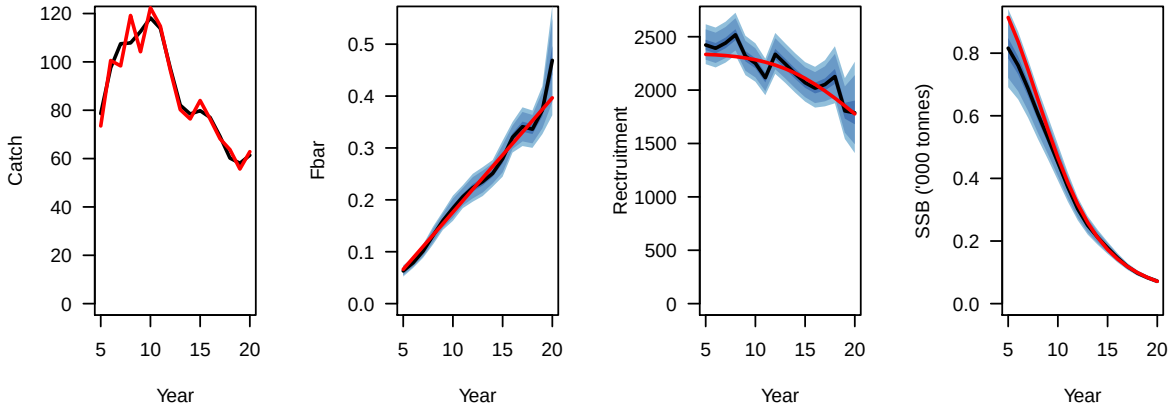

Figure 16: Model residuals. Colours represent ages

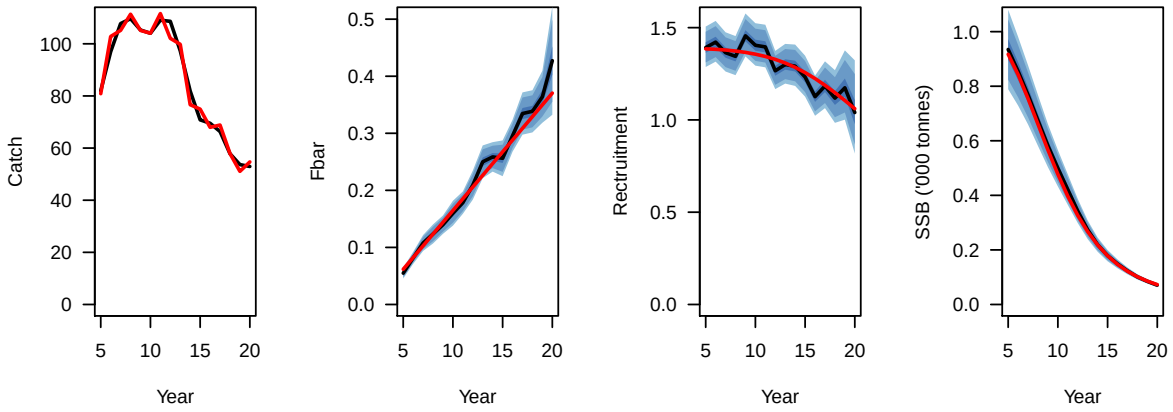

Figure 17: Model residuals. Colours represent ages

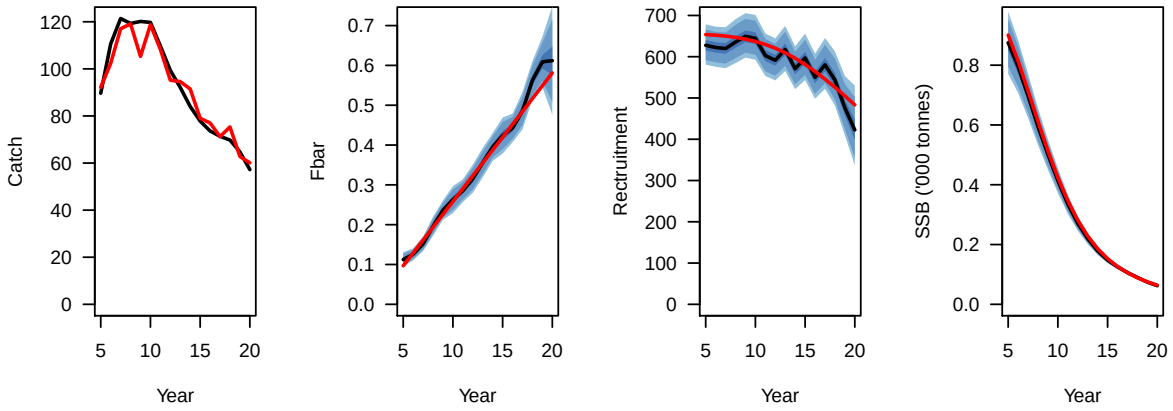

Figure 18: Model residuals. Colours represent ages

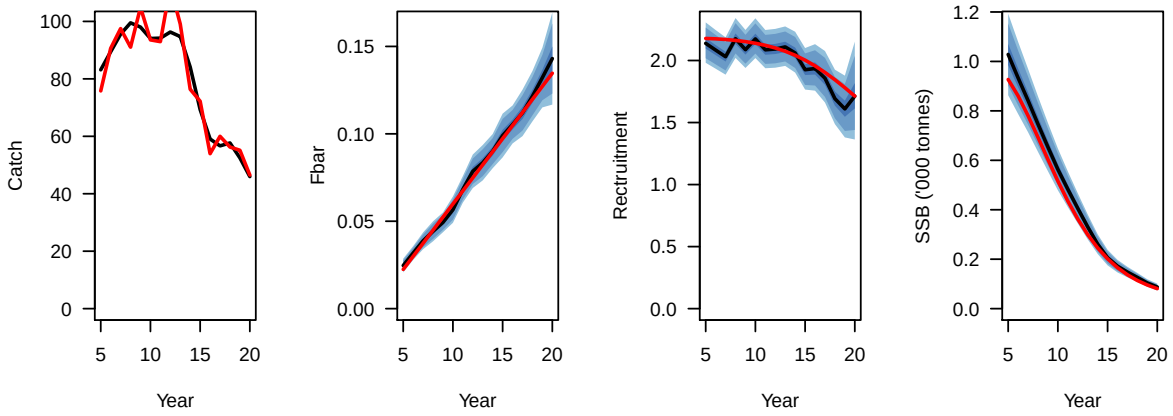

Figure 19: Model residuals. Colours represent ages

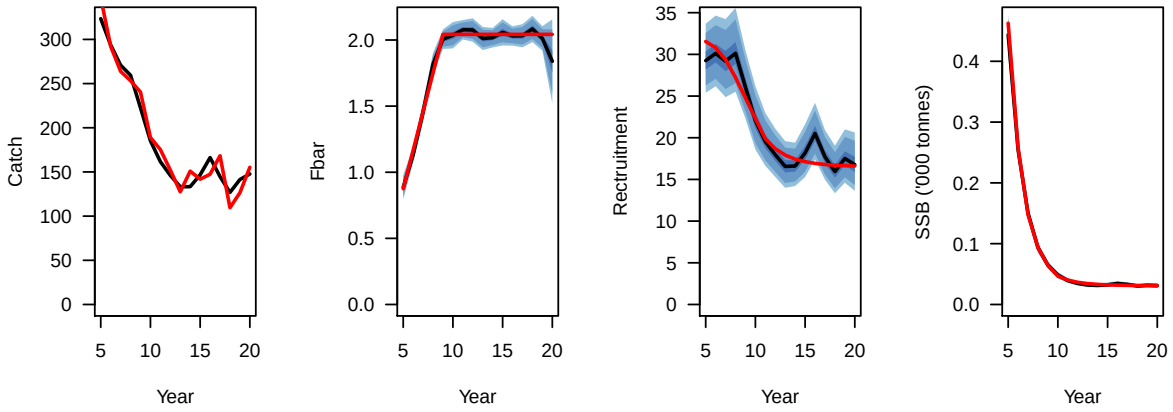

Figure 20: Model residuals. Colours represent ages

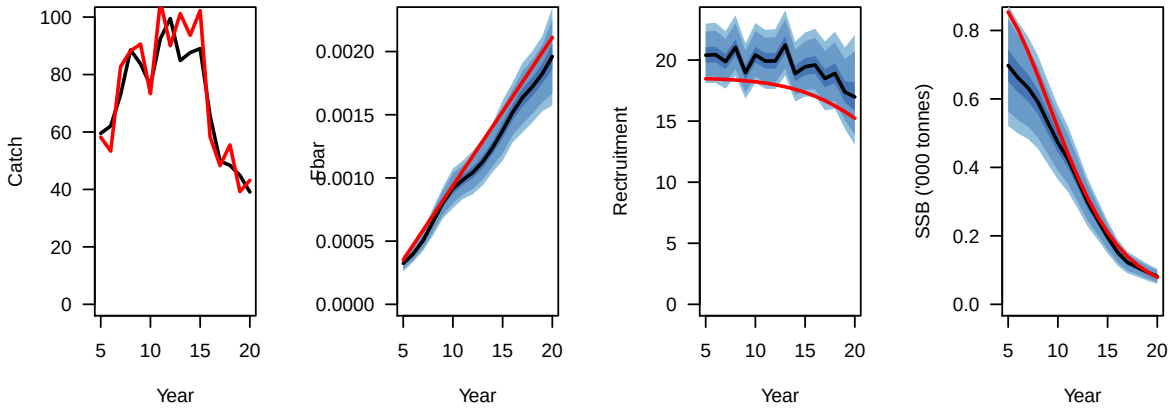

Figure 21: Model residuals. Colours represent ages

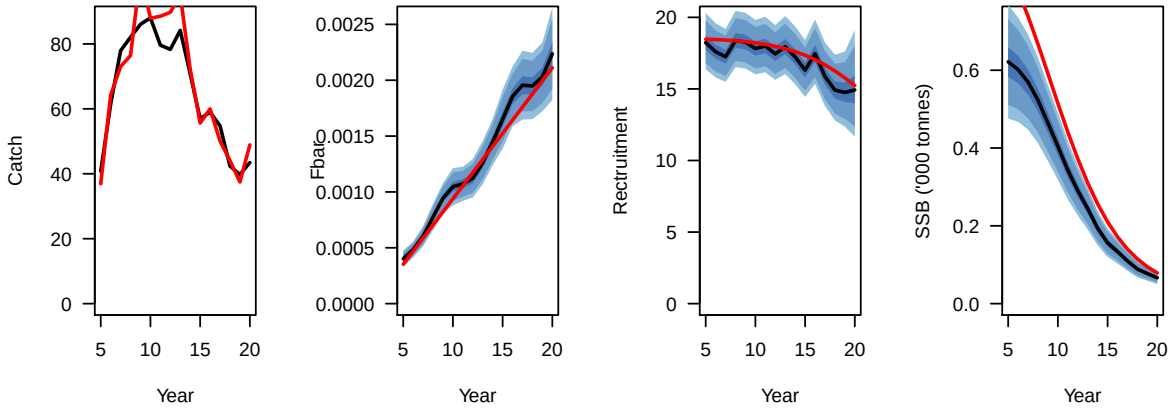

Figure 22: Model residuals. Colours represent ages

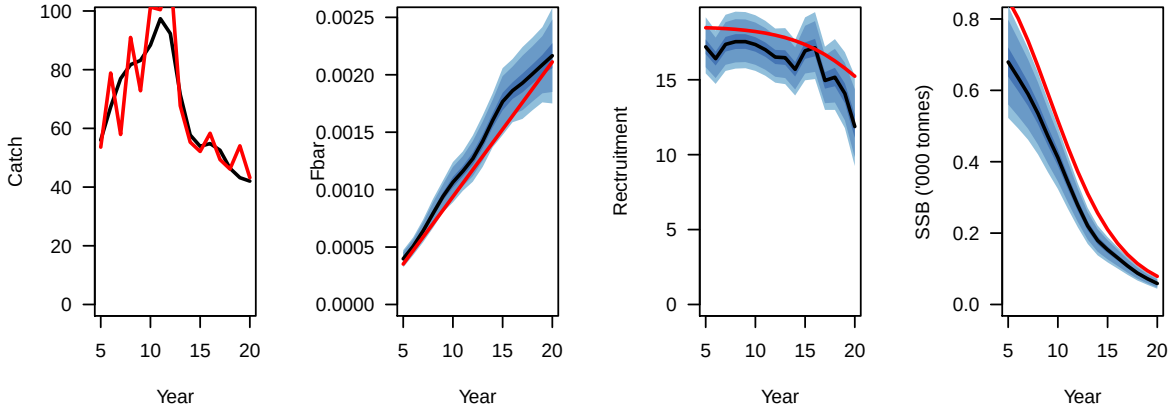

Figure 23: Model residuals. Colours represent ages

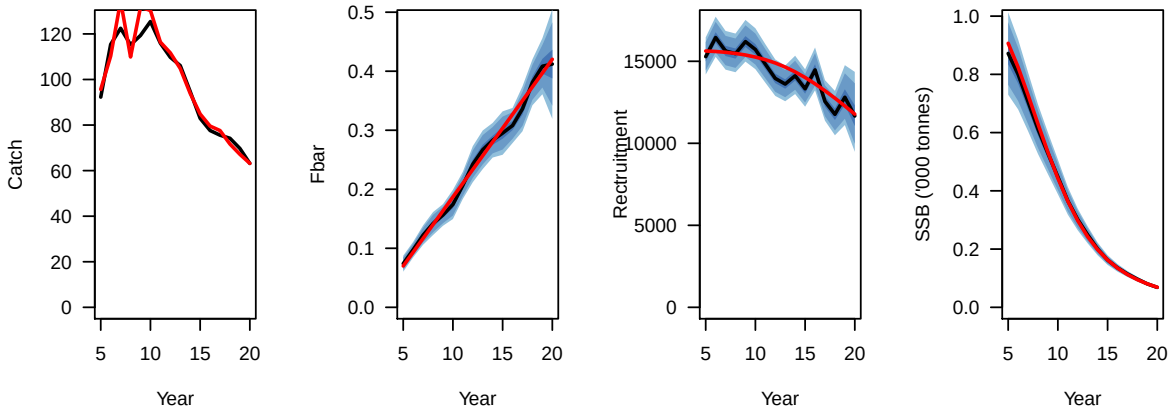

Figure 24: Model residuals. Colours represent ages

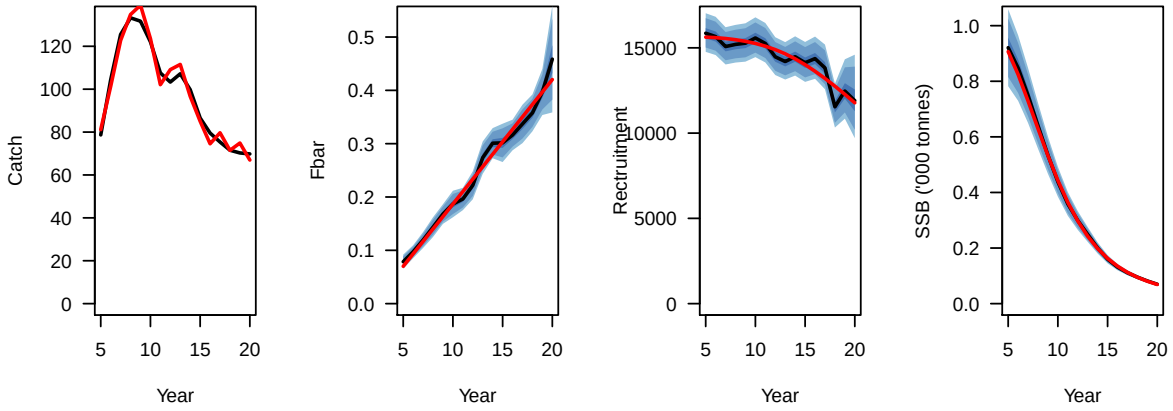

Figure 25: Model residuals. Colours represent ages

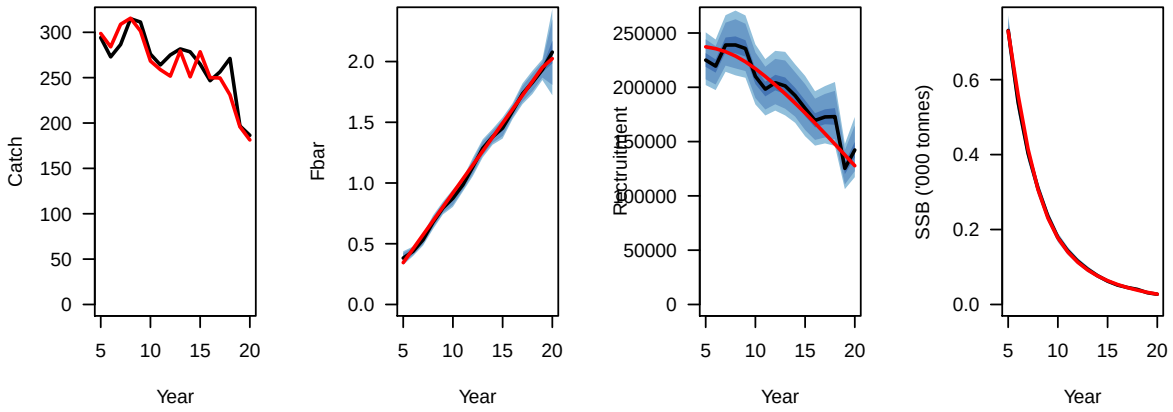

Figure 26: Model residuals. Colours represent ages

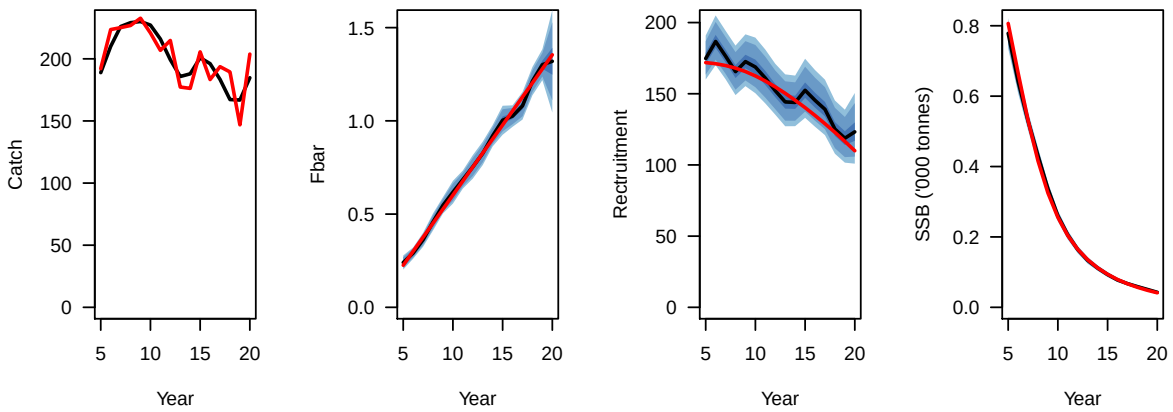

Figure 27: Model residuals. Colours represent ages

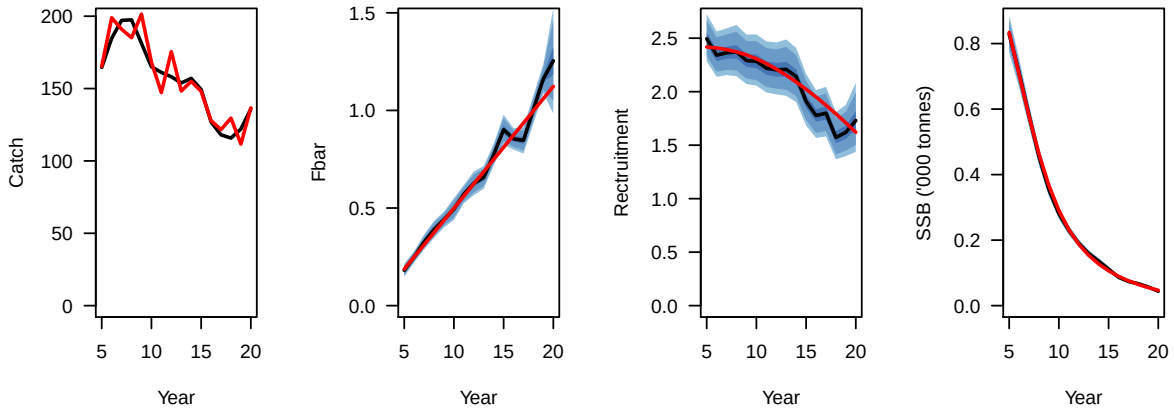

Figure 28: Model residuals. Colours represent ages

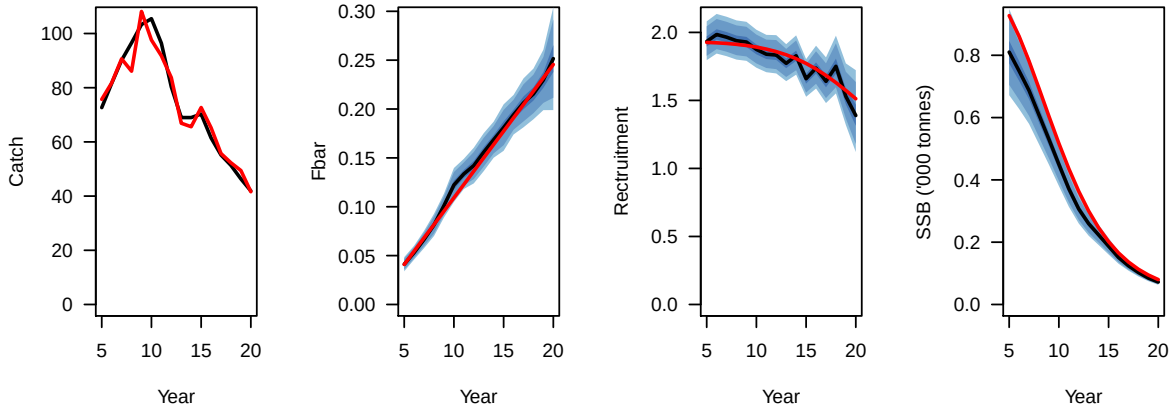

Figure 29: Model residuals. Colours represent ages

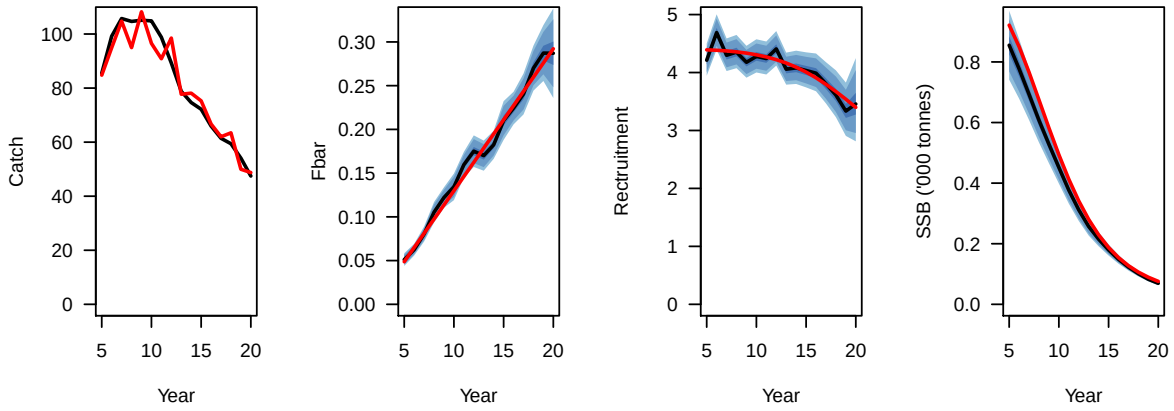

Figure 30: Model residuals. Colours represent ages

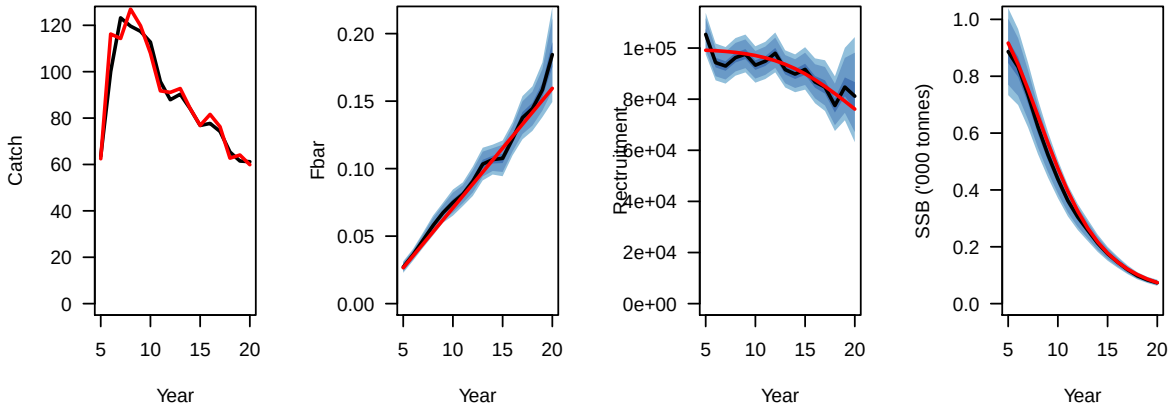

Figure 31: Model residuals. Colours represent ages

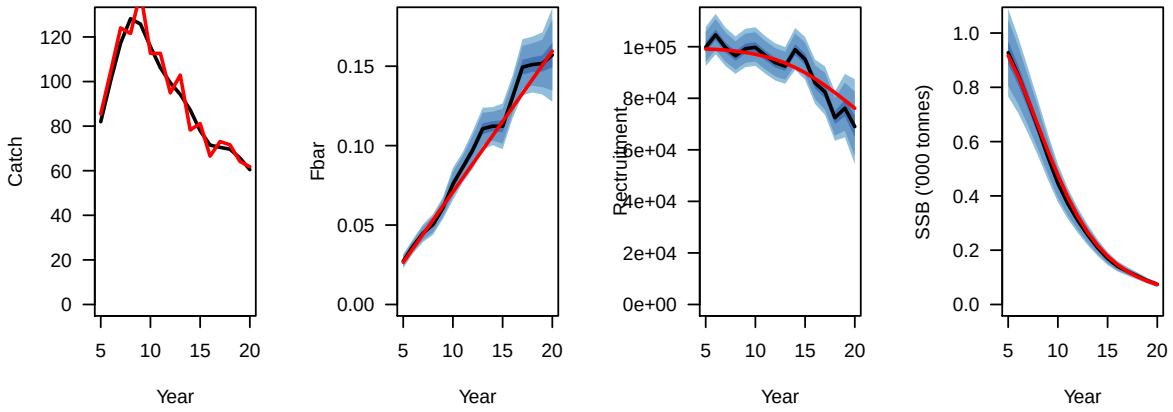

Figure 32: Model residuals. Colours represent ages

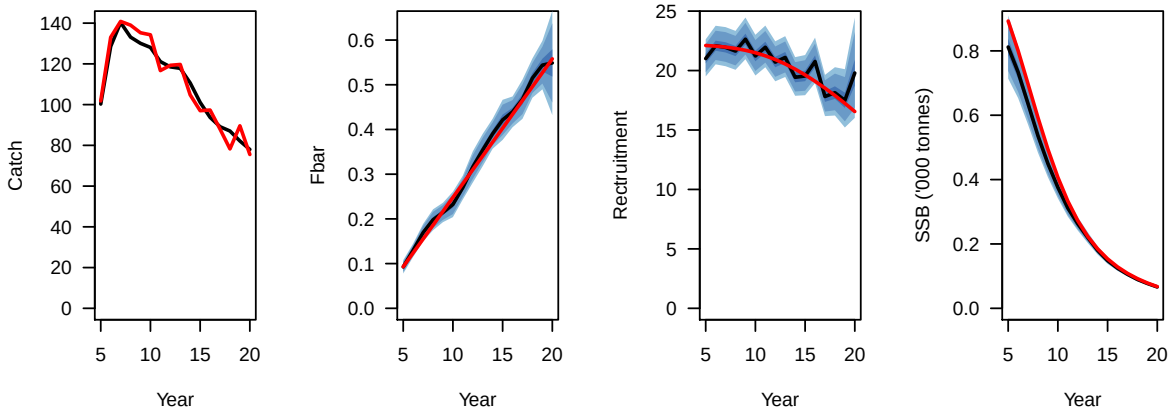

Figure 33: Model residuals. Colours represent ages

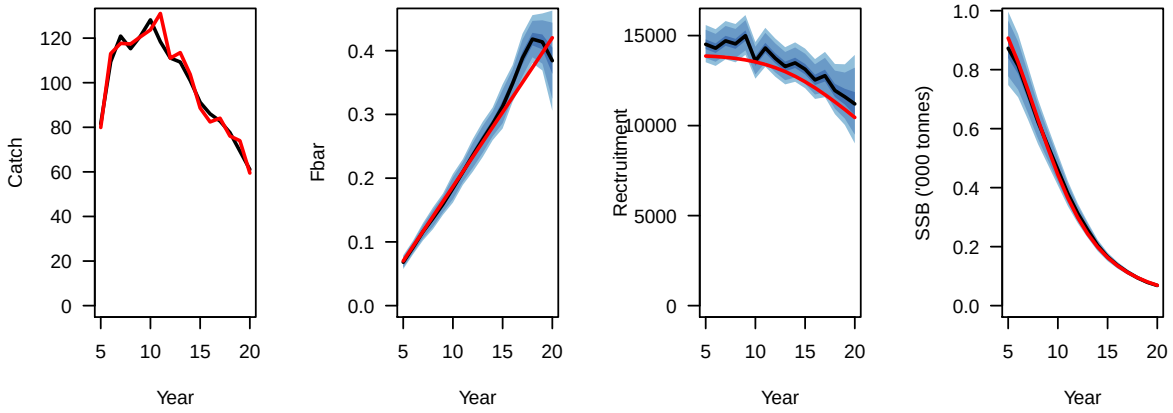

Figure 34: Model residuals. Colours represent ages

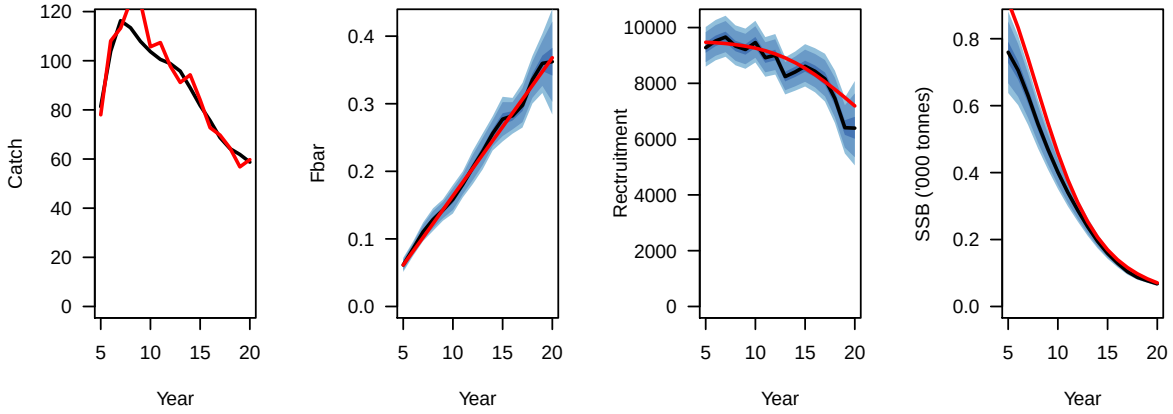

Figure 35: Model residuals. Colours represent ages

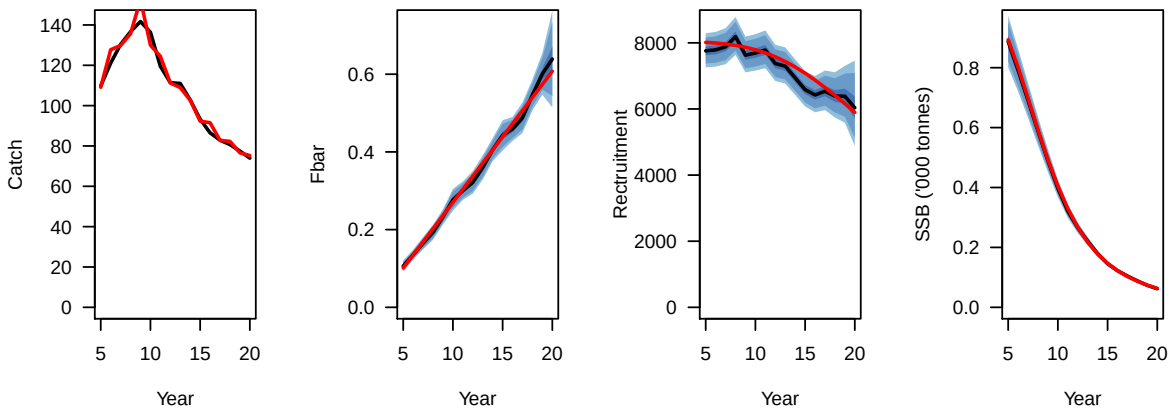

Figure 36: Model residuals. Colours represent ages

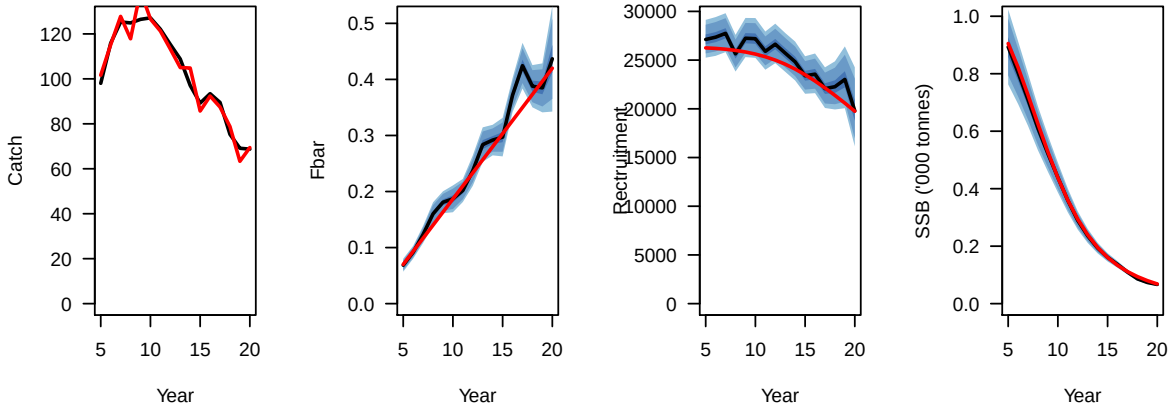

Figure 37: Model residuals. Colours represent ages

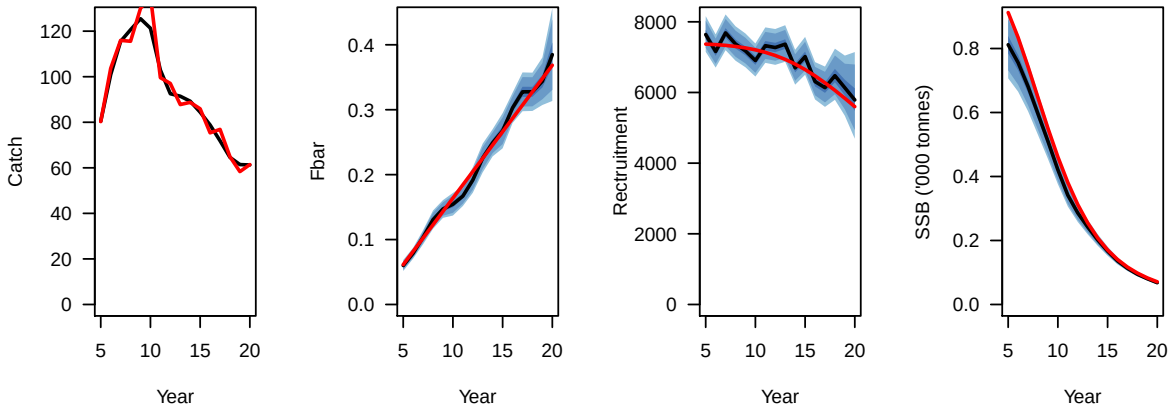

Figure 38: Model residuals. Colours represent ages

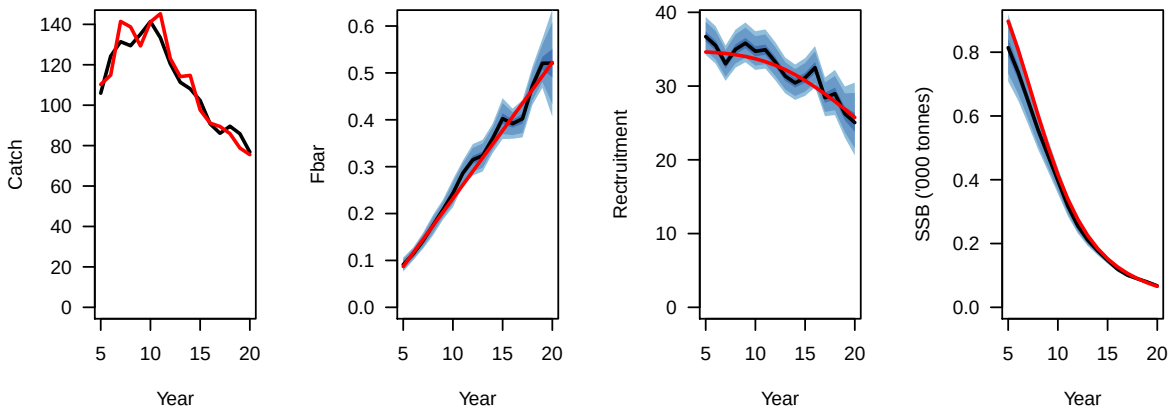

Figure 39: Model residuals. Colours represent ages

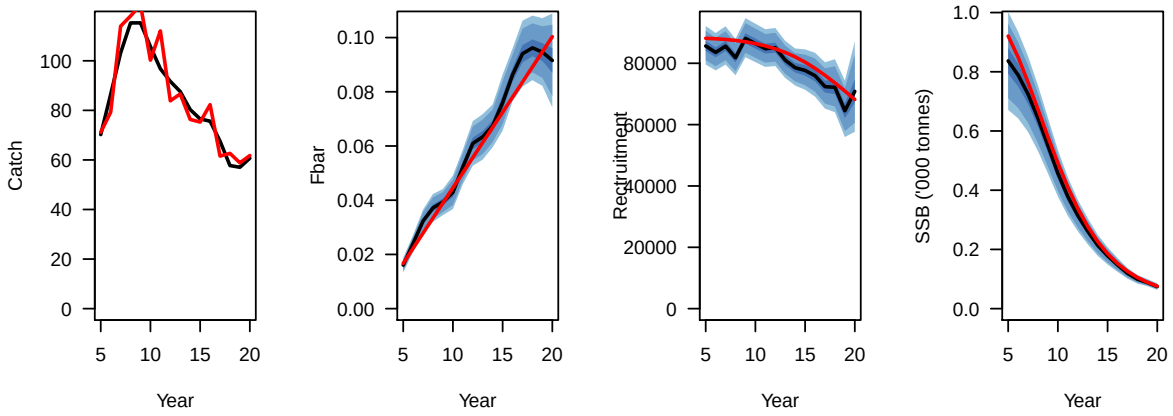

Figure 40: Model residuals. Colours represent ages

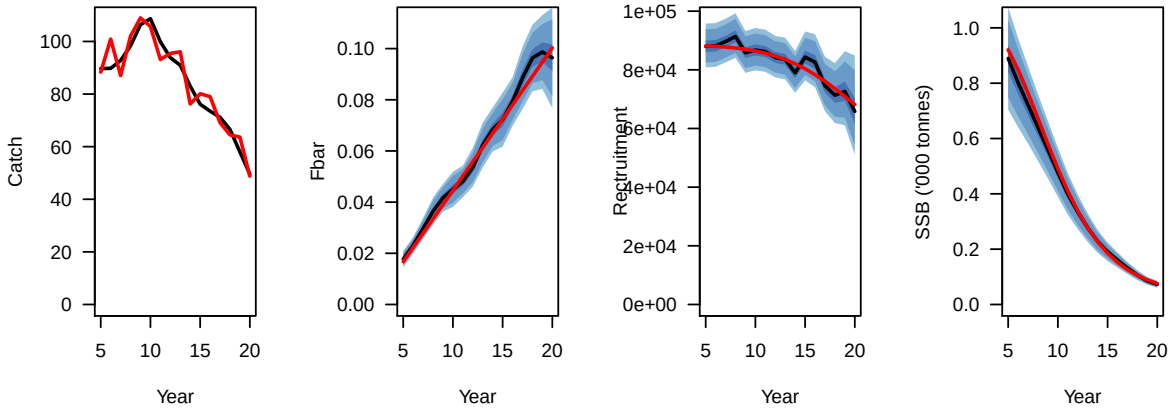

Figure 41: Model residuals. Colours represent ages

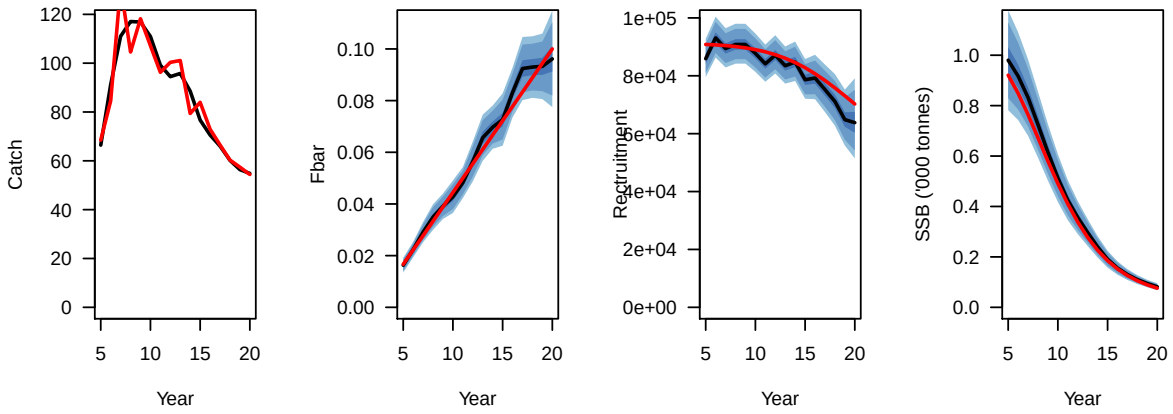

Figure 42: Model residuals. Colours represent ages

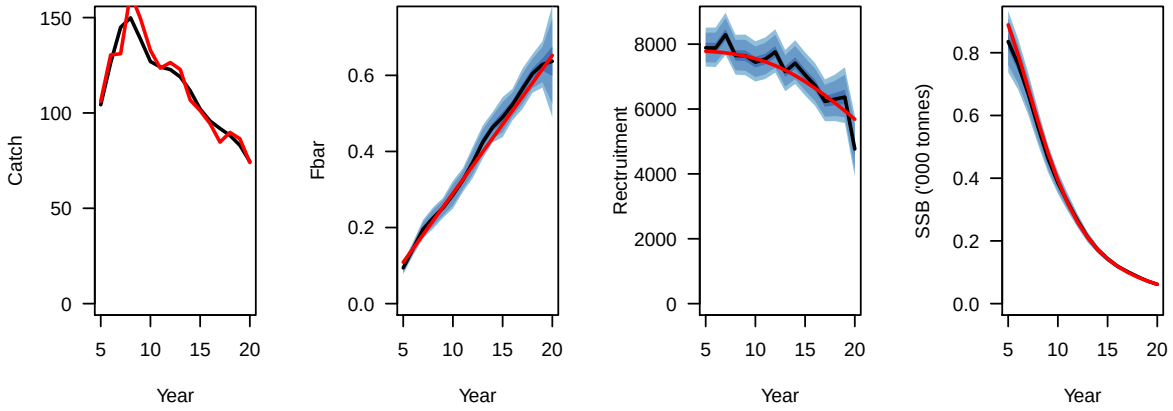

Figure 43: Model residuals. Colours represent ages

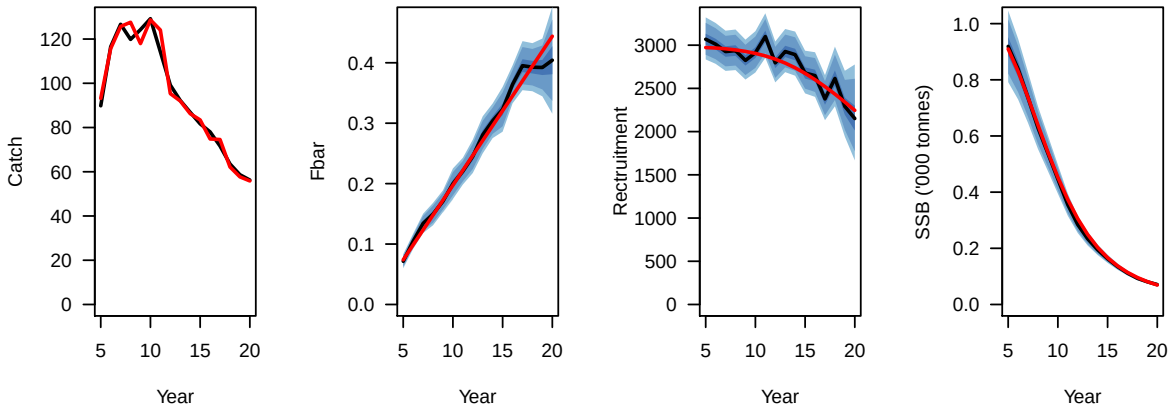

Figure 44: Model residuals. Colours represent ages

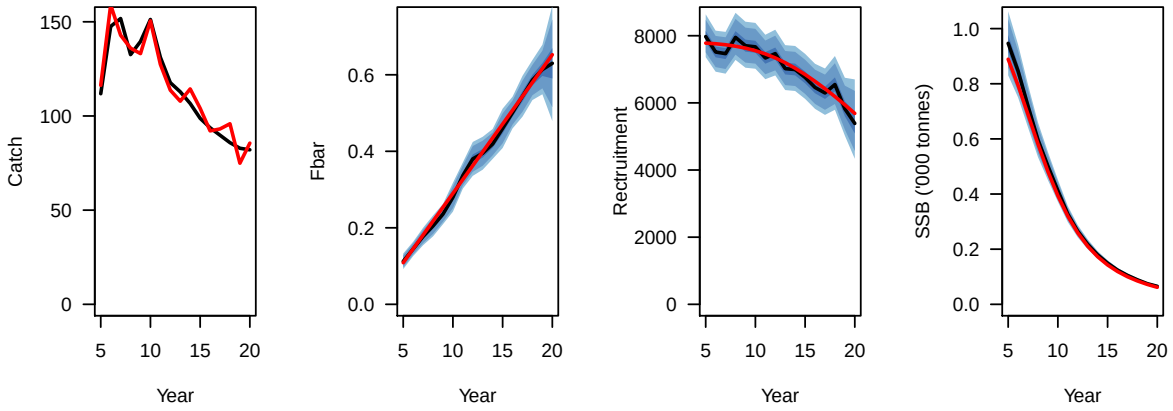

Figure 45: Model residuals. Colours represent ages

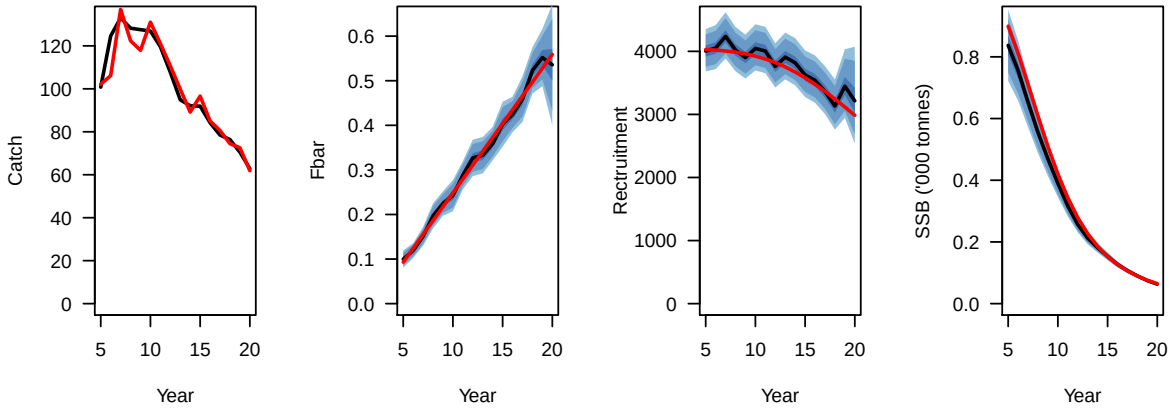

Figure 46: Model residuals. Colours represent ages

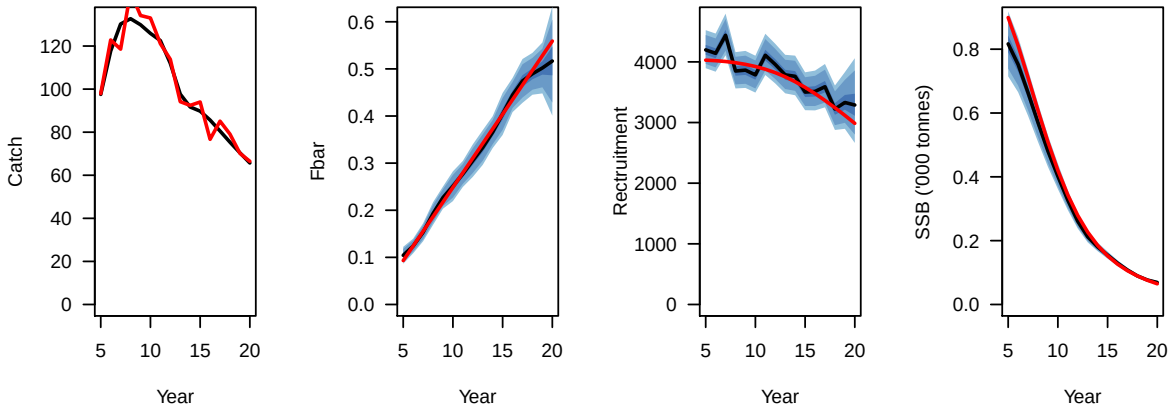

Figure 47: Model residuals. Colours represent ages

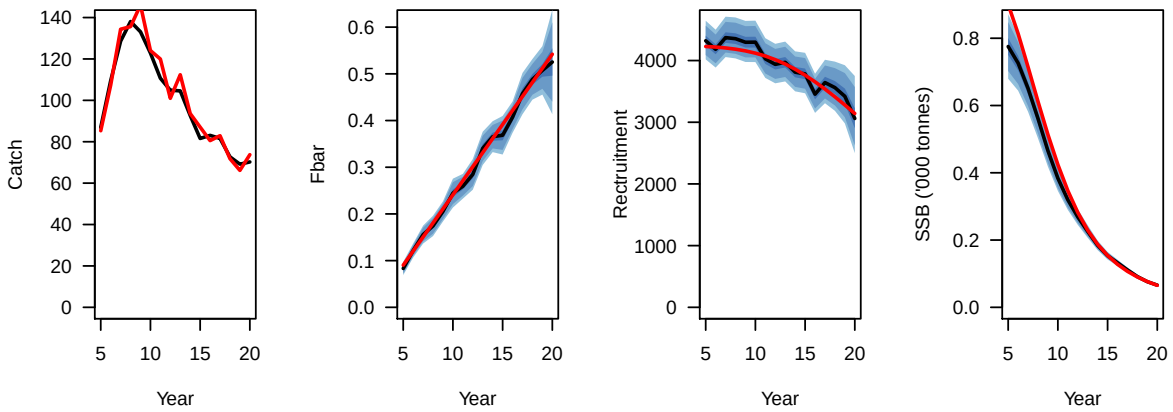

Figure 48: Model residuals. Colours represent ages

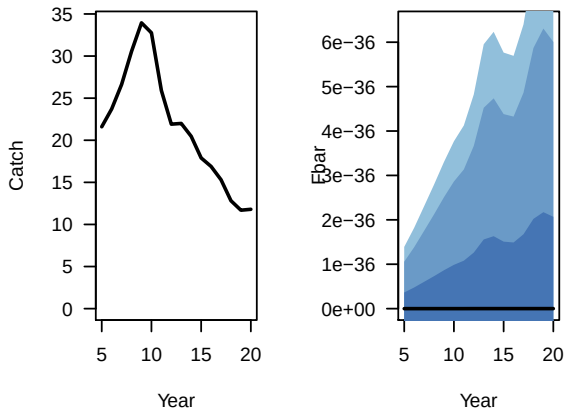

Figure 49: Model residuals. Colours represent ages

```
## Error:  need finite 'ylim' values
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Developing and stabilizing

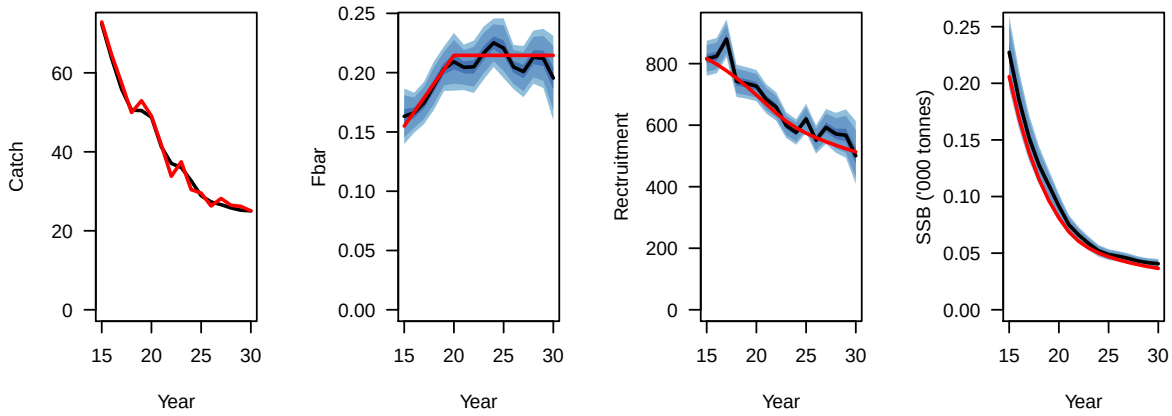


Figure 50: Model residuals. Colors represent ages

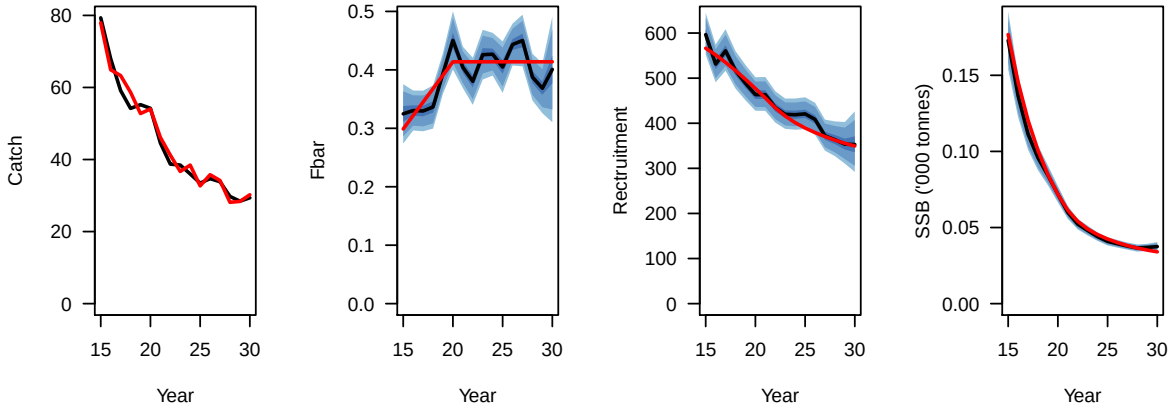


Figure 51: Model residuals. Colors represent ages

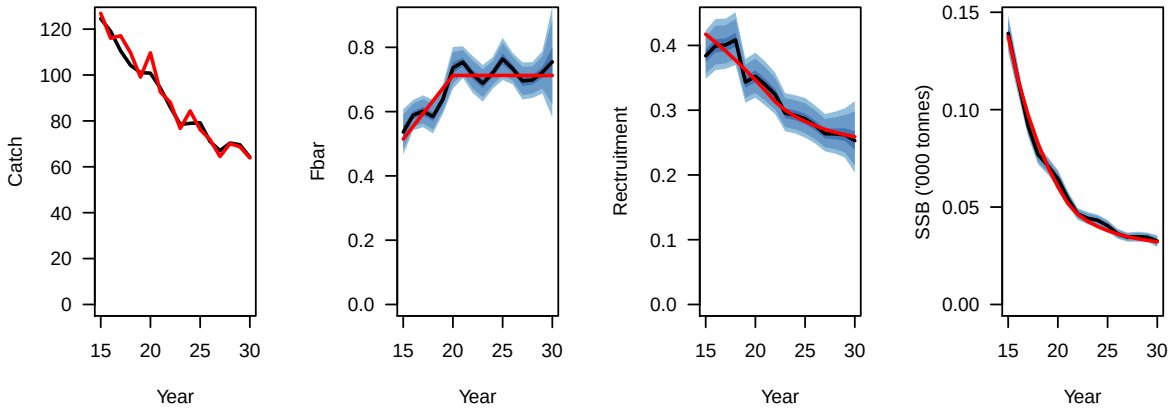


Figure 52: Model residuals. Colors represent ages

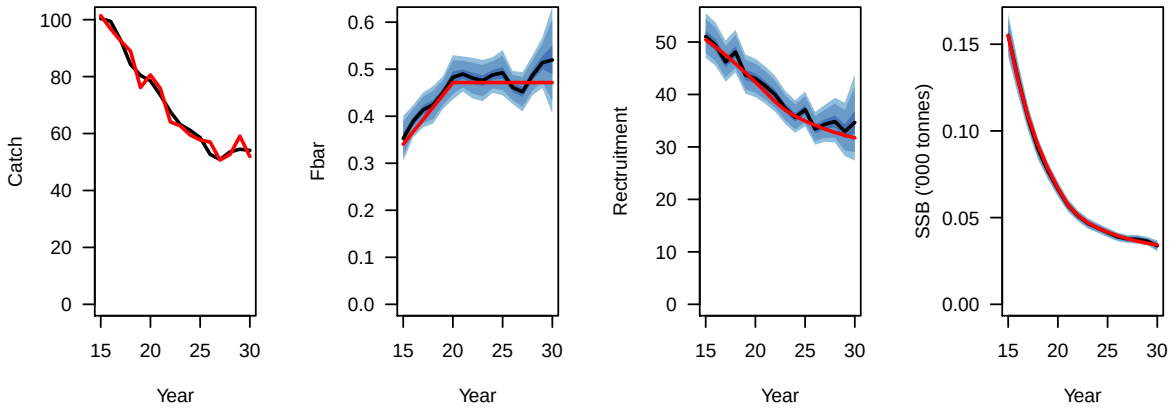


Figure 53: Model residuals. Colors represent ages

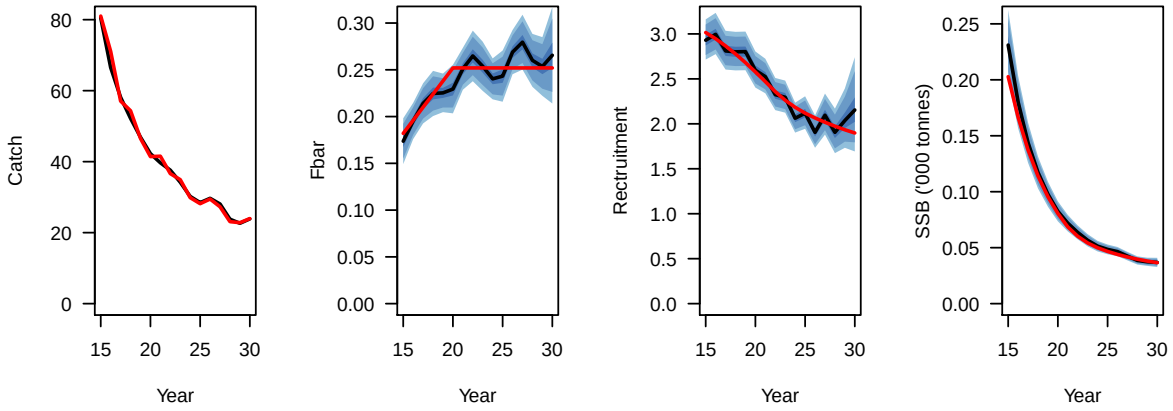


Figure 54: Model residuals. Colors represent ages

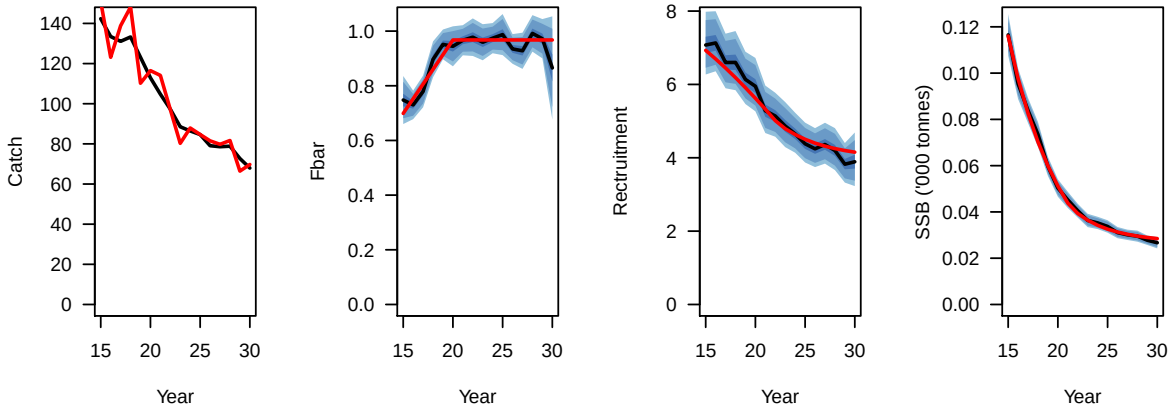


Figure 55: Model residuals. Colors represent ages

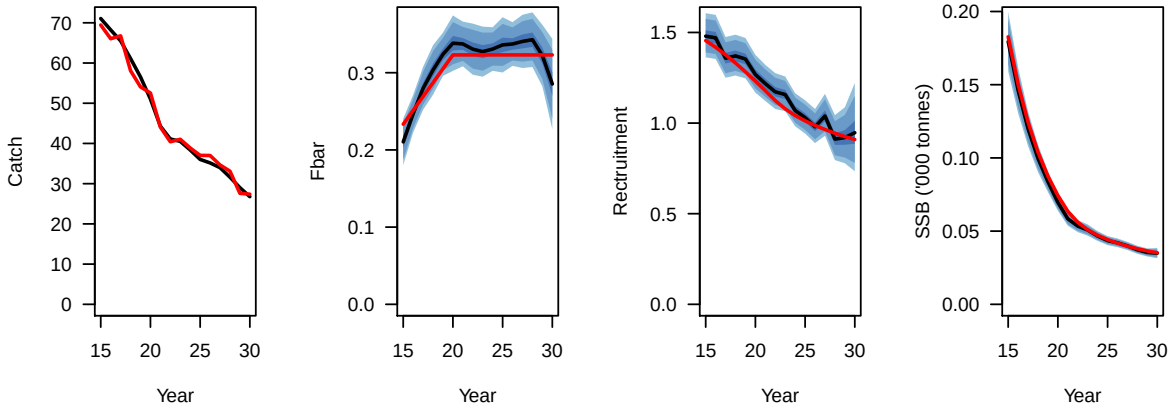


Figure 56: Model residuals. Colors represent ages

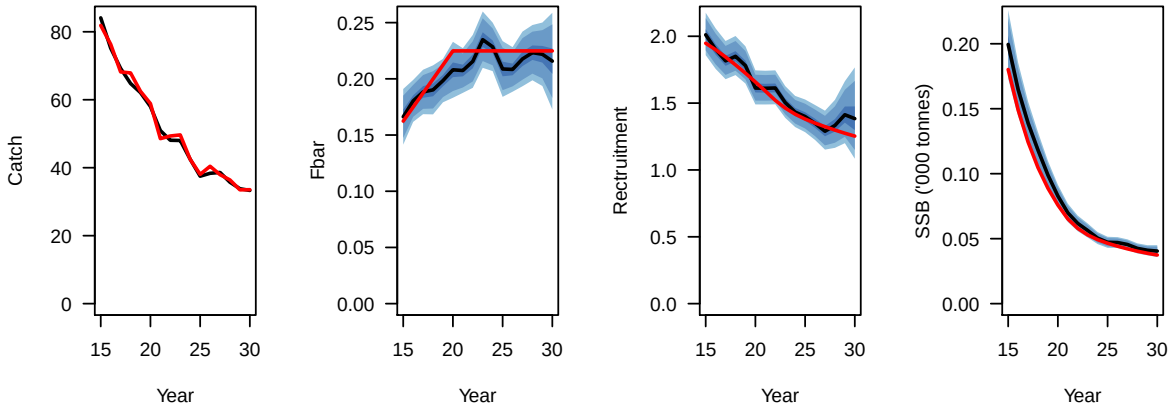


Figure 57: Model residuals. Colors represent ages

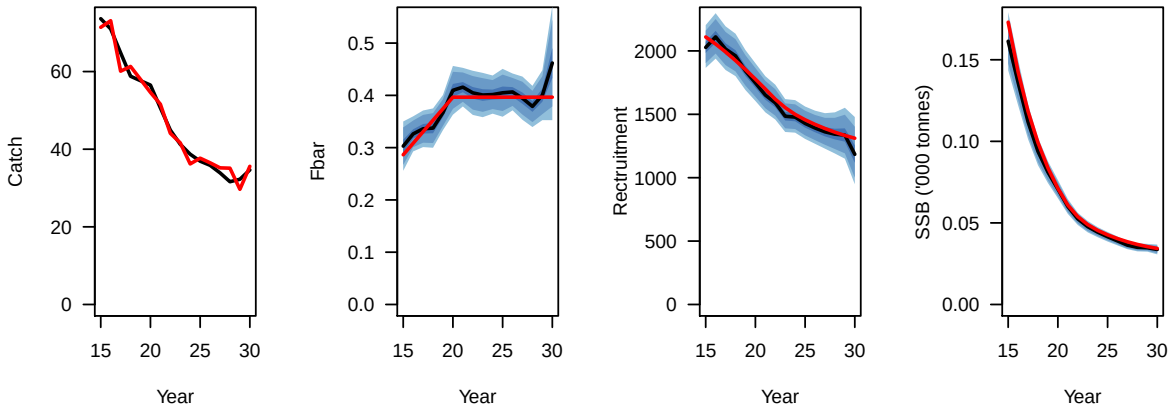


Figure 58: Model residuals. Colors represent ages

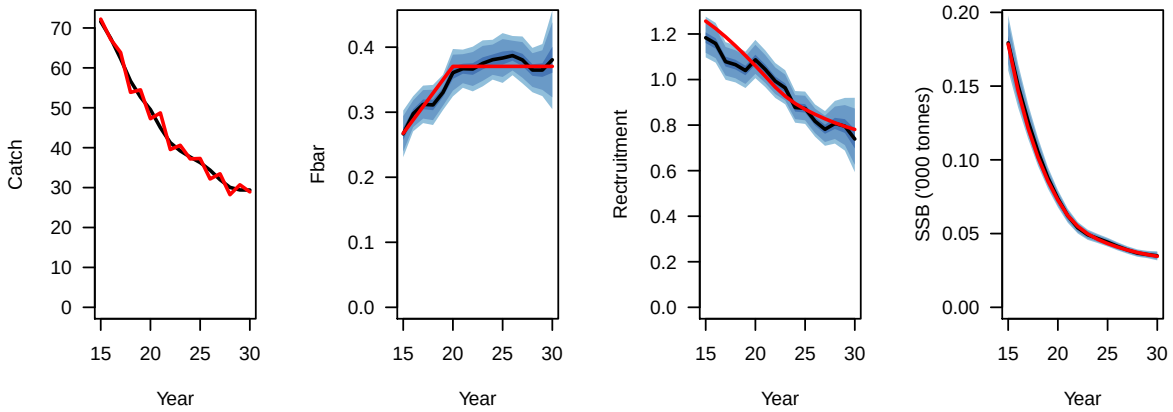


Figure 59: Model residuals. Colors represent ages

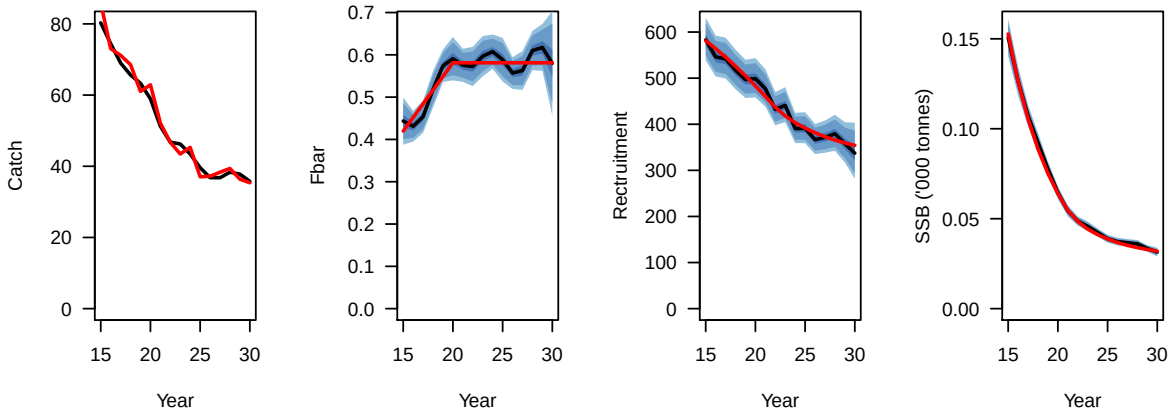


Figure 60: Model residuals. Colors represent ages

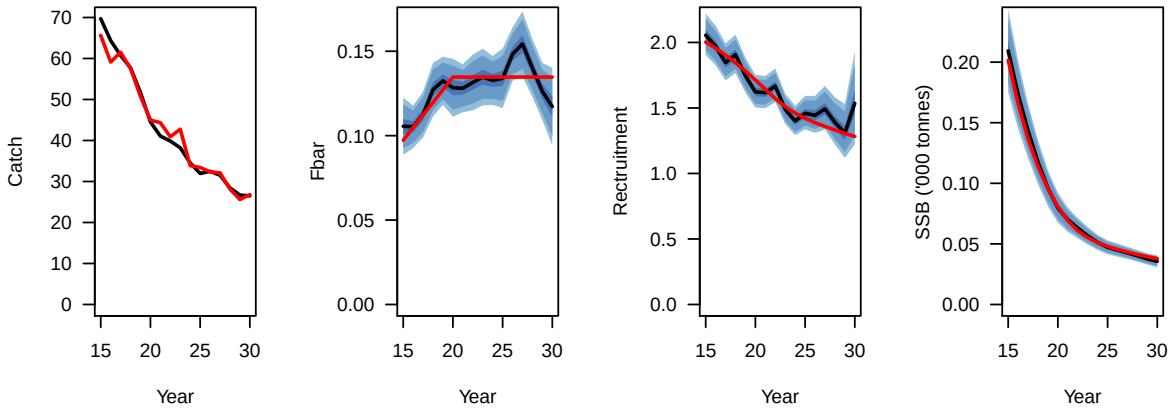


Figure 61: Model residuals. Colors represent ages

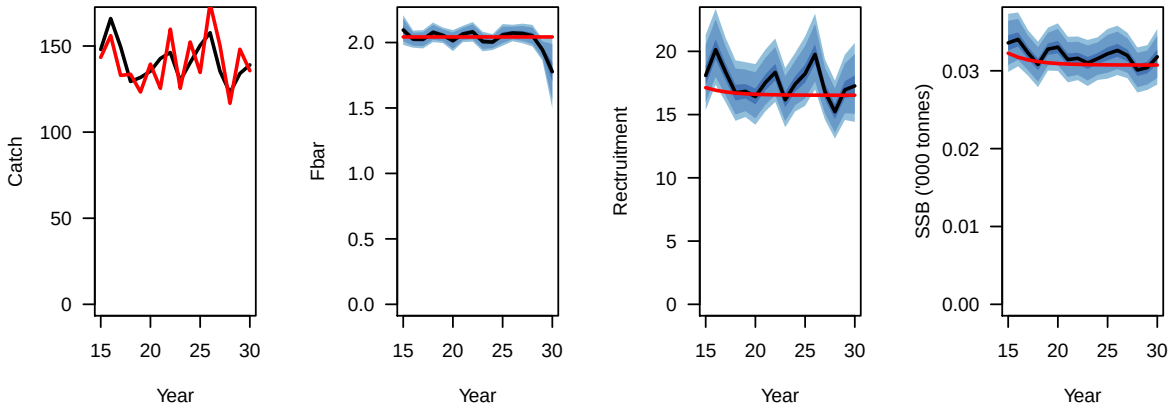


Figure 62: Model residuals. Colors represent ages

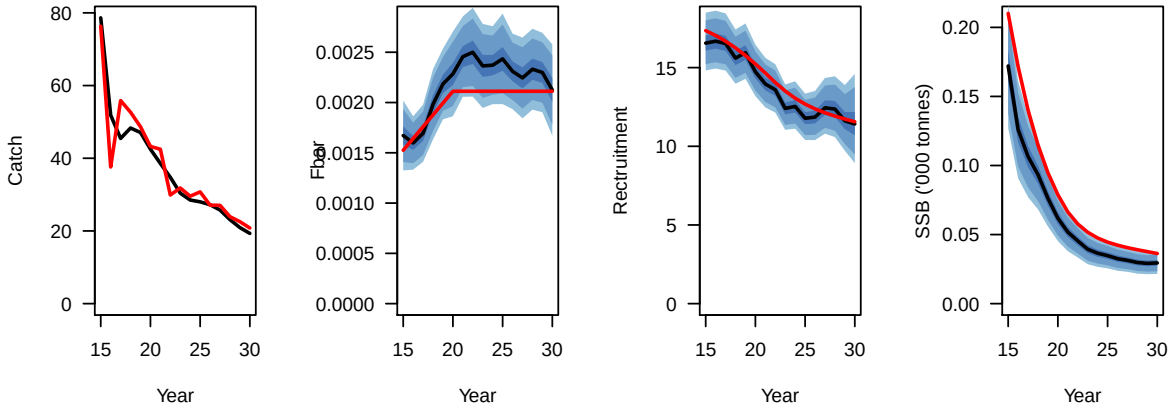


Figure 63: Model residuals. Colors represent ages

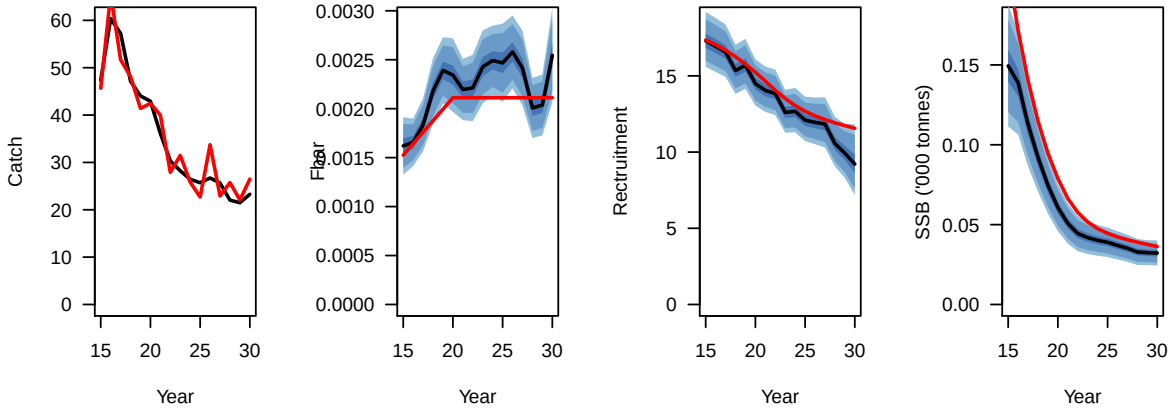


Figure 64: Model residuals. Colors represent ages

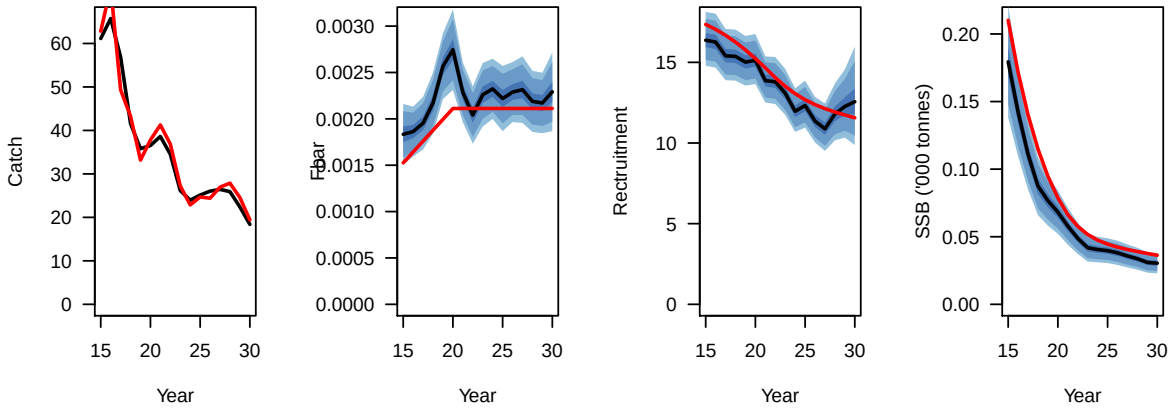


Figure 65: Model residuals. Colors represent ages

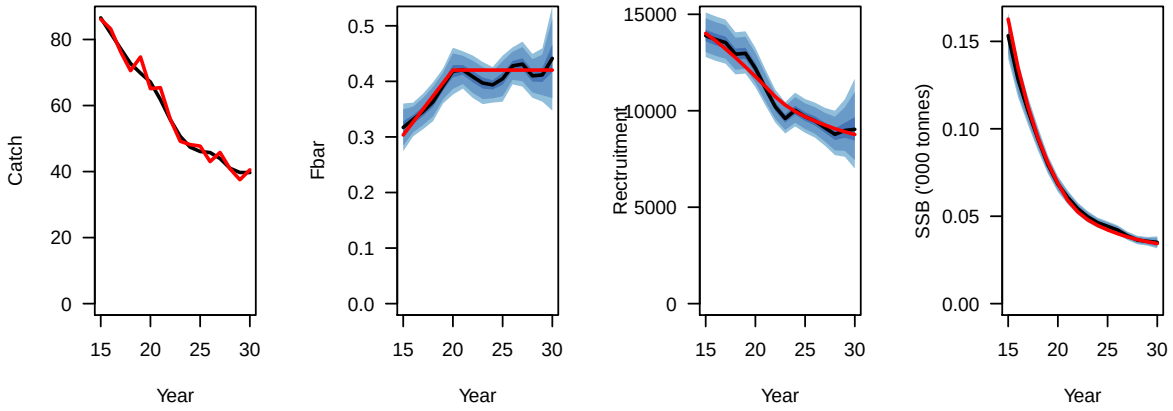


Figure 66: Model residuals. Colors represent ages

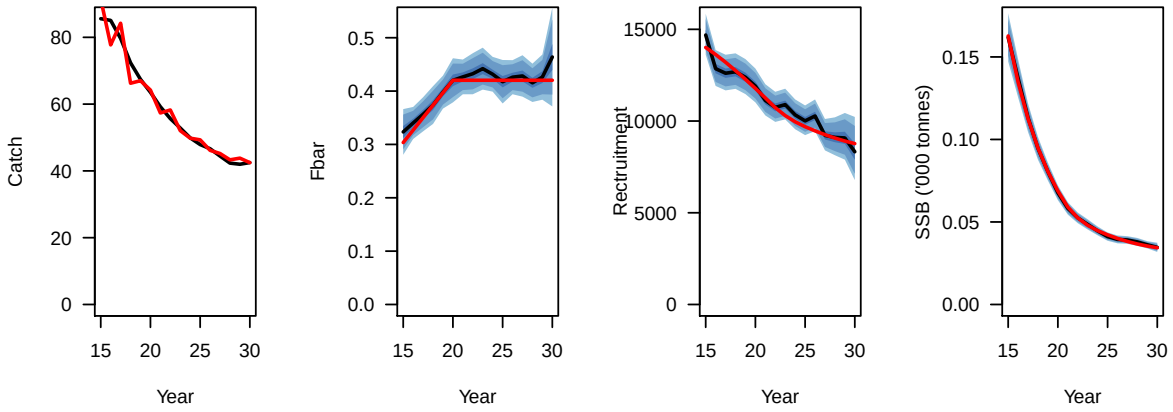


Figure 67: Model residuals. Colors represent ages

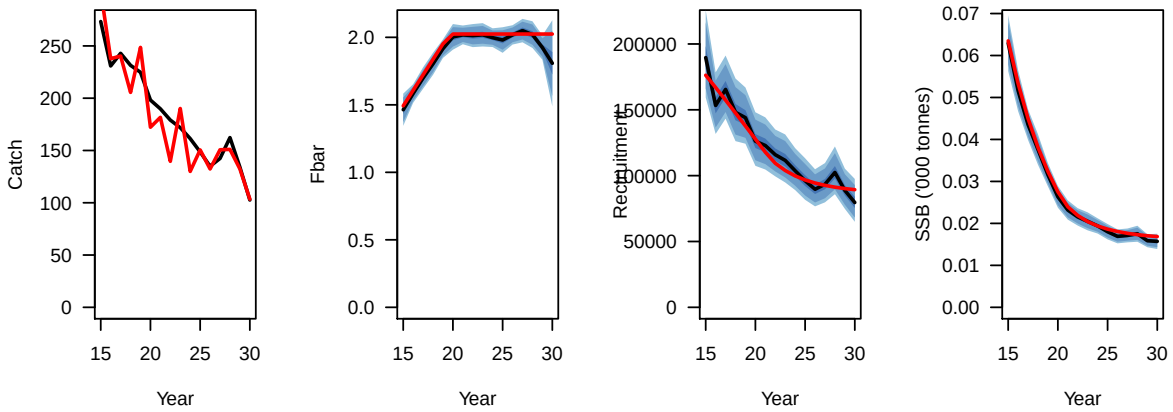


Figure 68: Model residuals. Colors represent ages

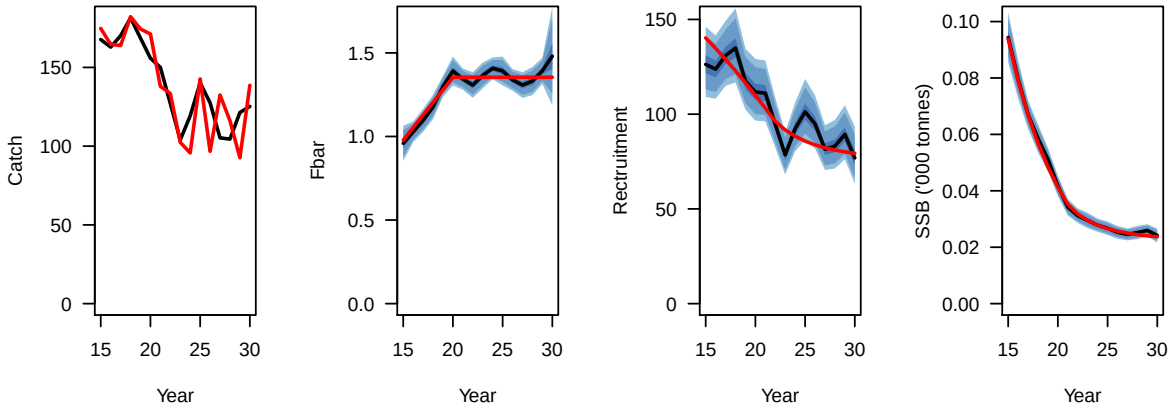


Figure 69: Model residuals. Colors represent ages

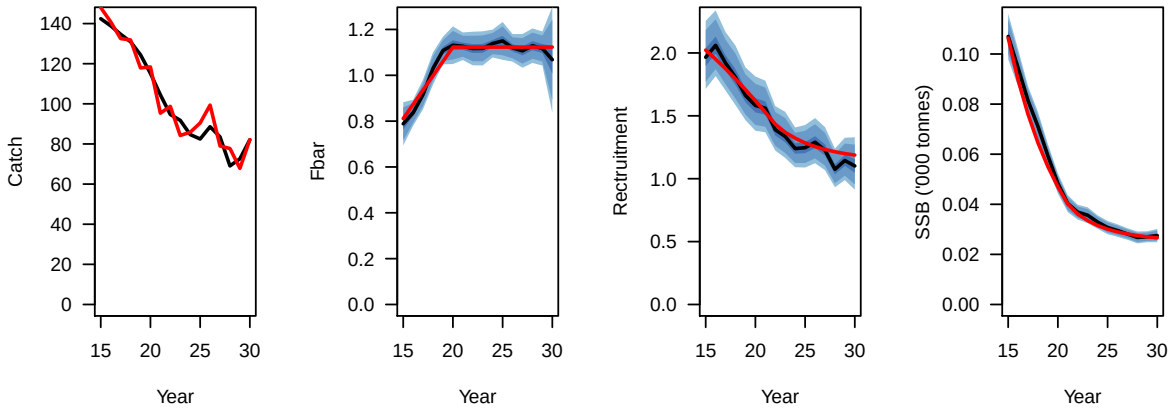


Figure 70: Model residuals. Colors represent ages

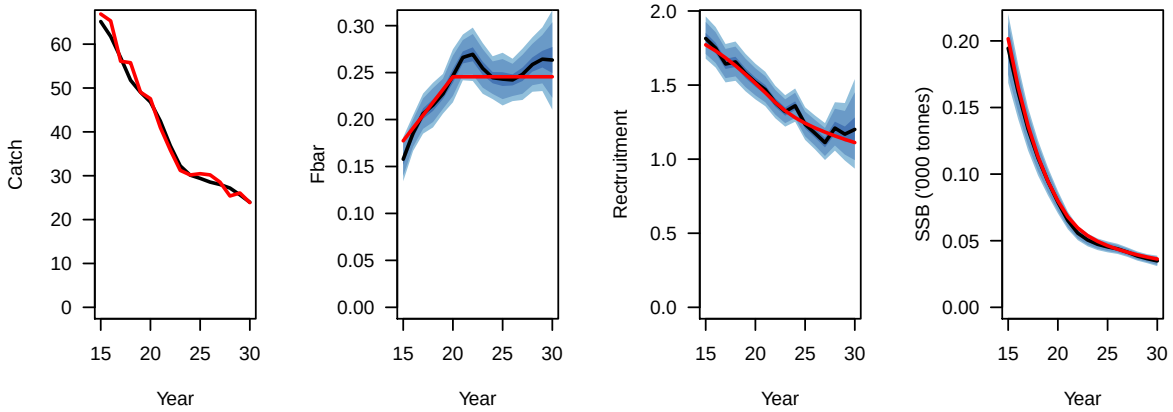


Figure 71: Model residuals. Colors represent ages

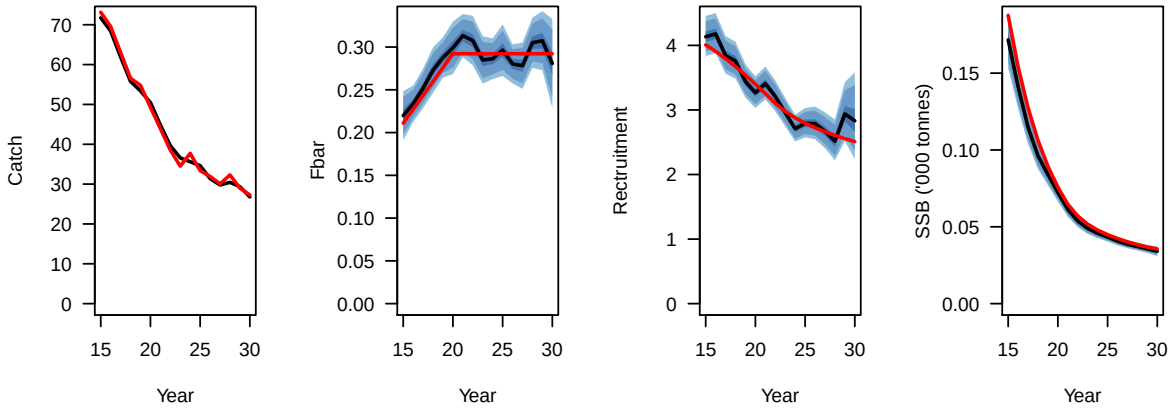


Figure 72: Model residuals. Colors represent ages

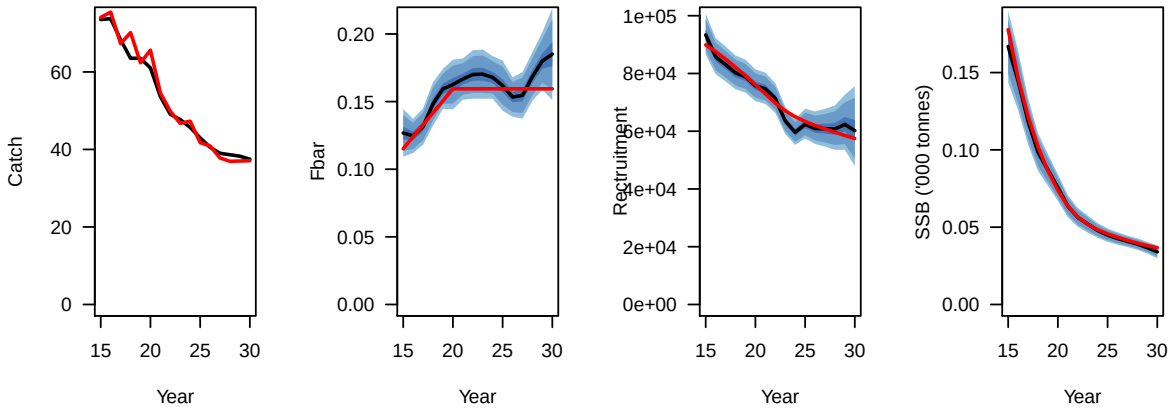


Figure 73: Model residuals. Colors represent ages

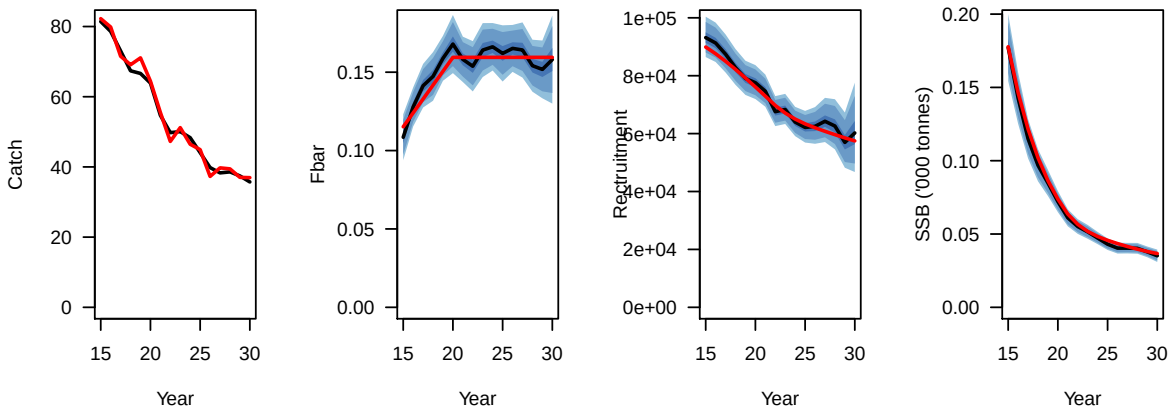


Figure 74: Model residuals. Colors represent ages

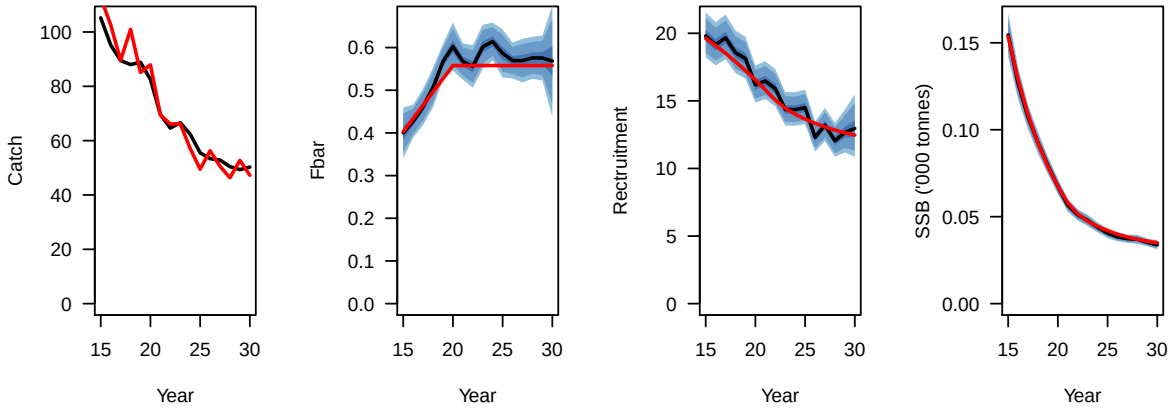


Figure 75: Model residuals. Colors represent ages

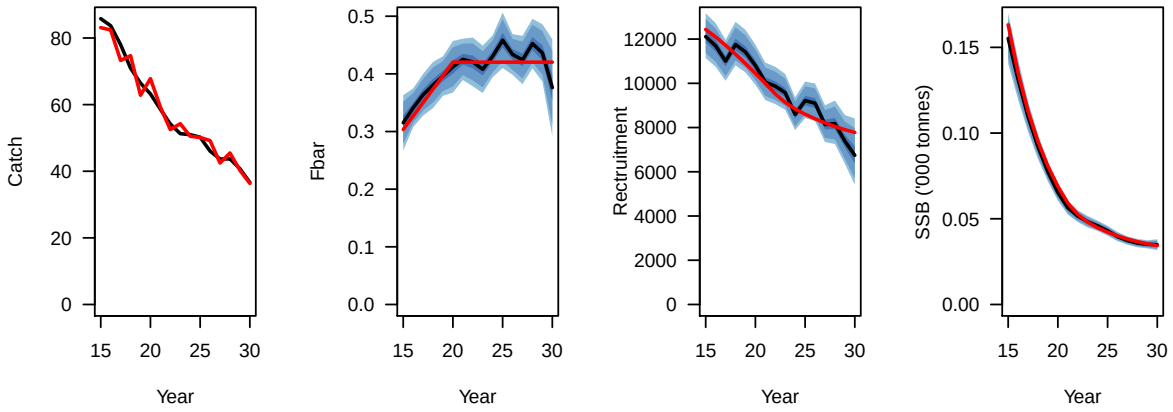


Figure 76: Model residuals. Colors represent ages

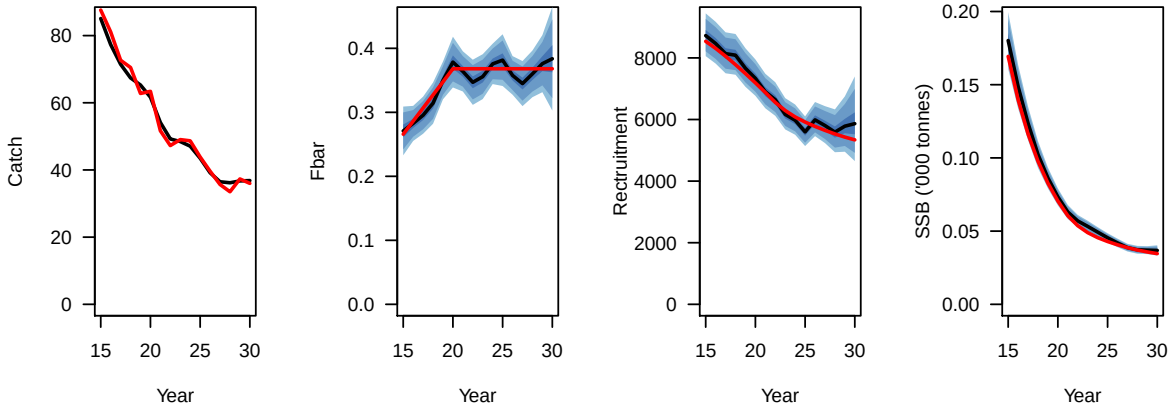


Figure 77: Model residuals. Colors represent ages

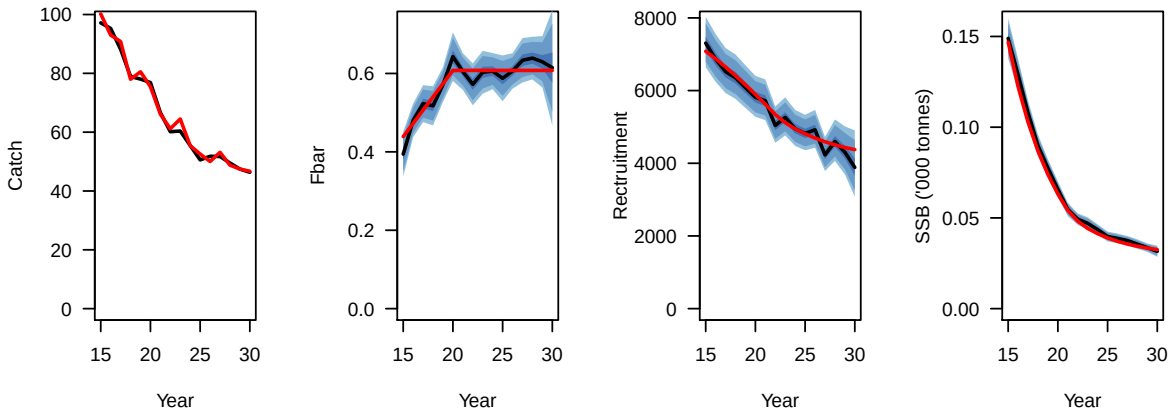


Figure 78: Model residuals. Colors represent ages

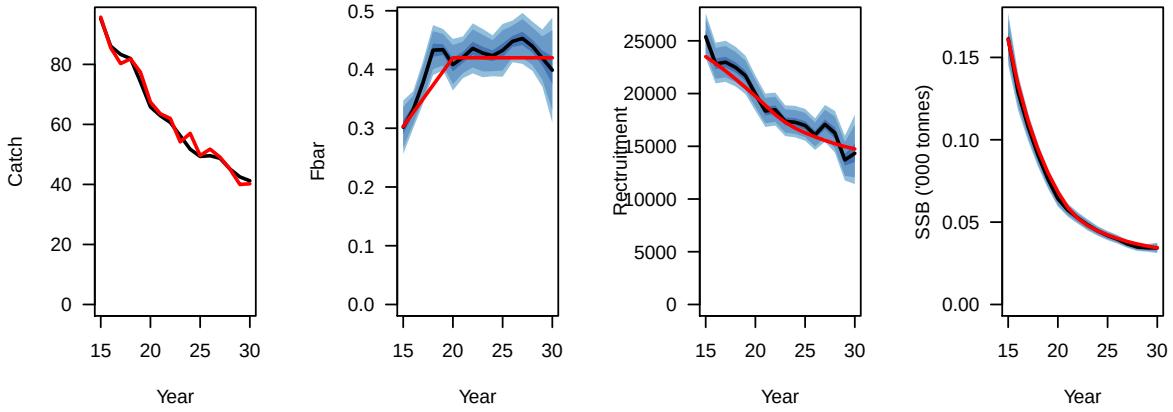


Figure 79: Model residuals. Colors represent ages

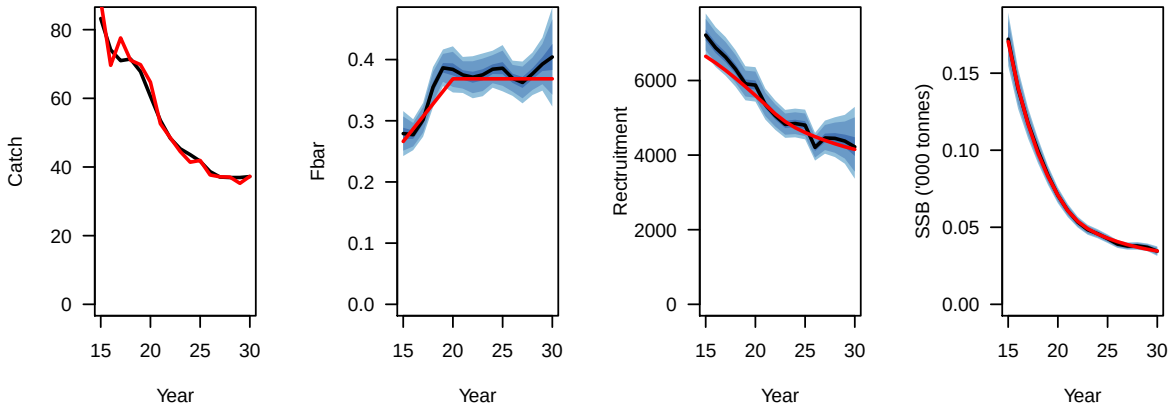


Figure 80: Model residuals. Colors represent ages

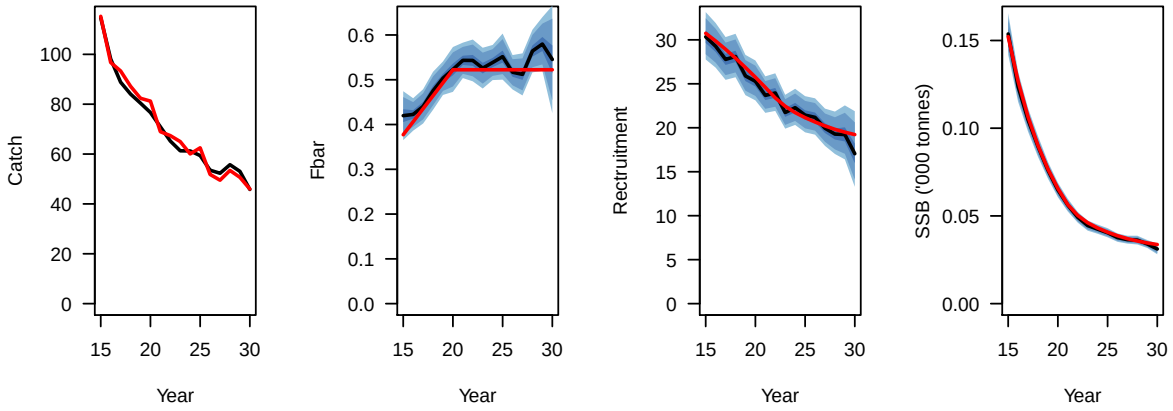


Figure 81: Model residuals. Colors represent ages

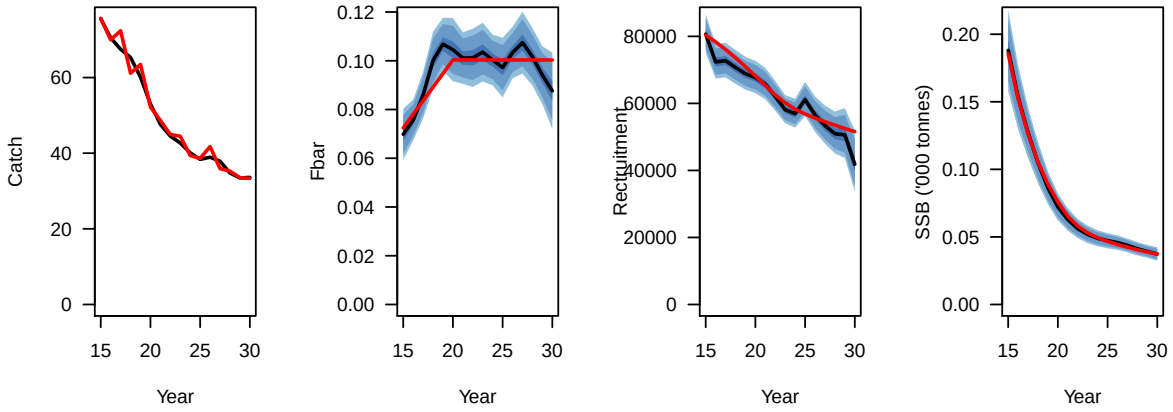


Figure 82: Model residuals. Colors represent ages

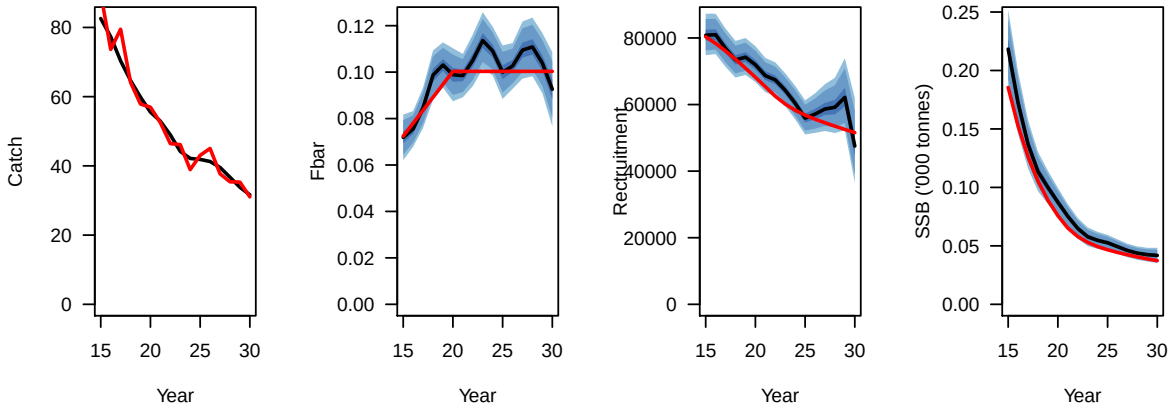


Figure 83: Model residuals. Colors represent ages

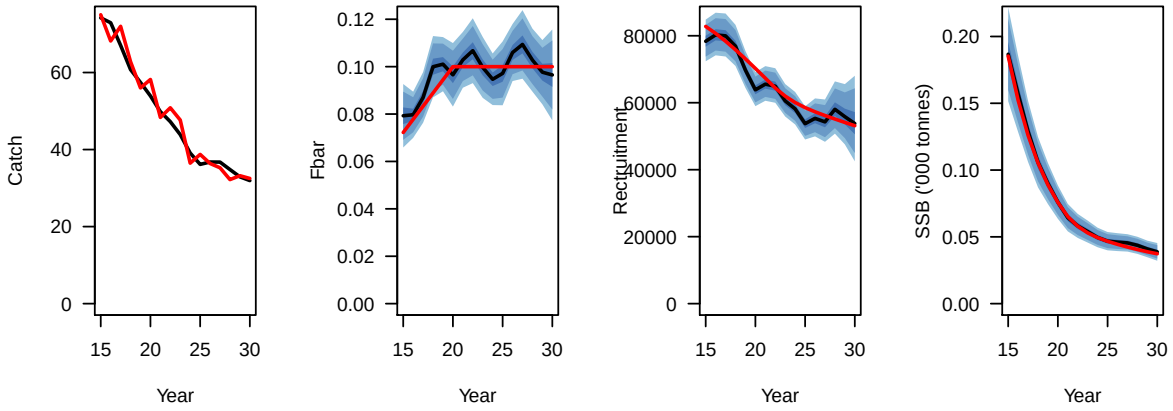


Figure 84: Model residuals. Colors represent ages

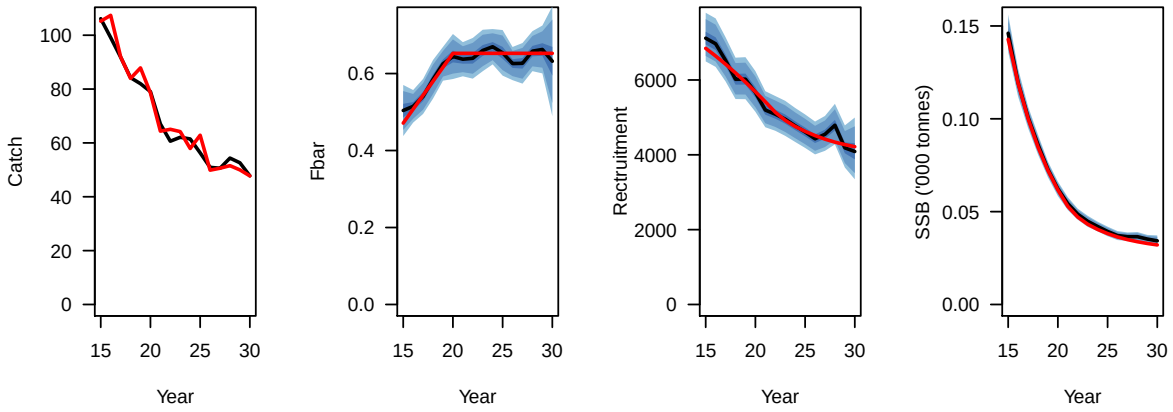


Figure 85: Model residuals. Colors represent ages

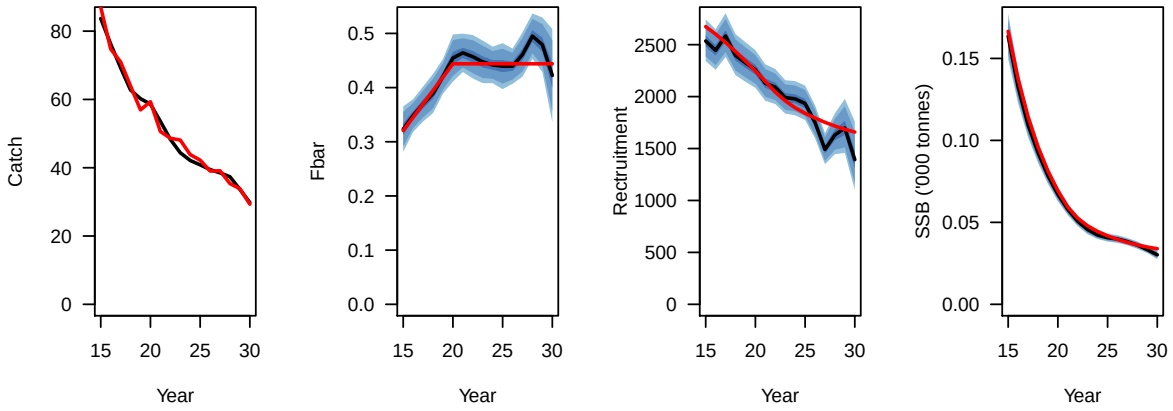


Figure 86: Model residuals. Colors represent ages

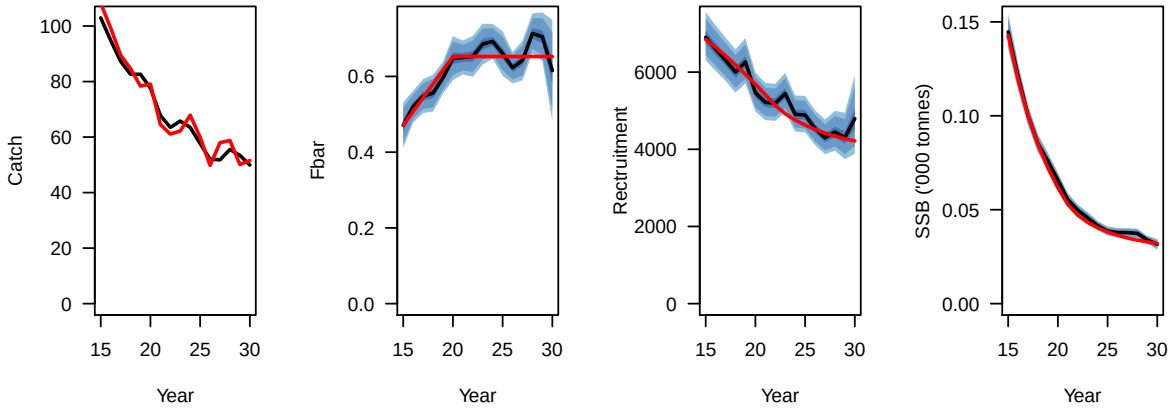


Figure 87: Model residuals. Colors represent ages

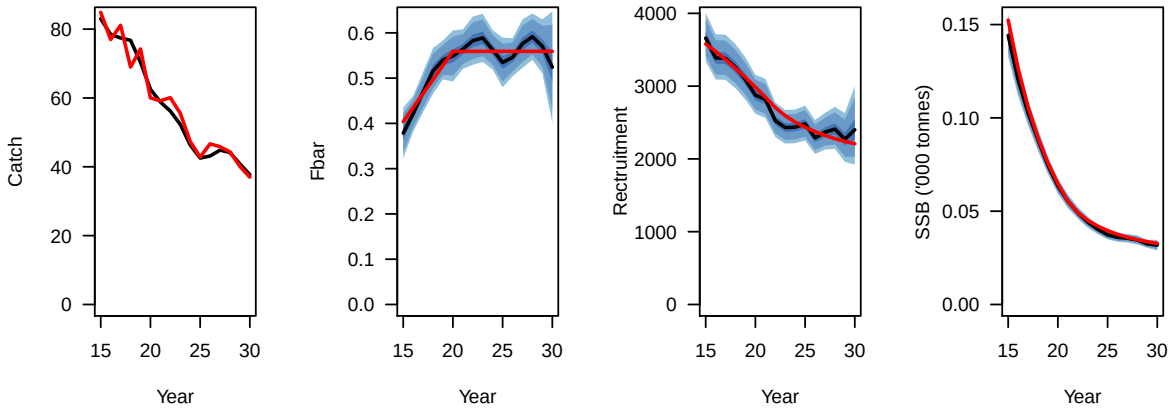


Figure 88: Model residuals. Colors represent ages

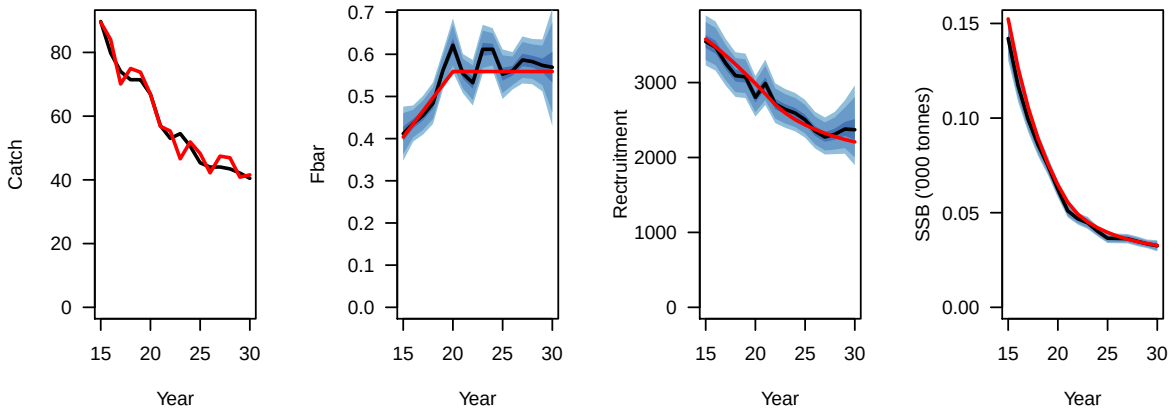


Figure 89: Model residuals. Colors represent ages

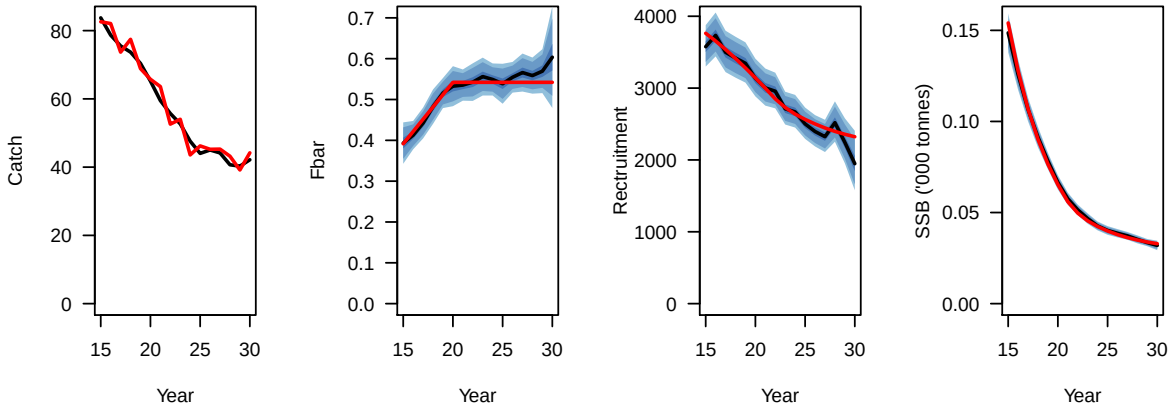


Figure 90: Model residuals. Colors represent ages

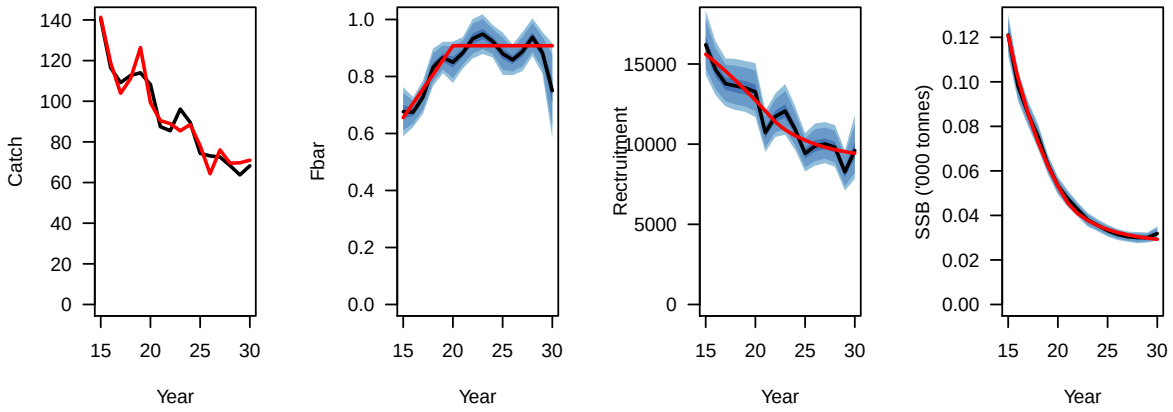


Figure 91: Model residuals. Colors represent ages

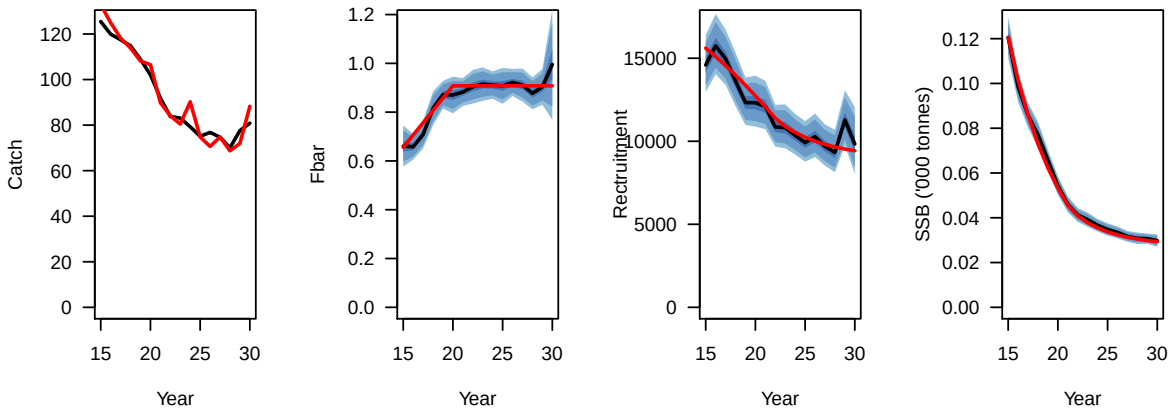


Figure 92: Model residuals. Colors represent ages

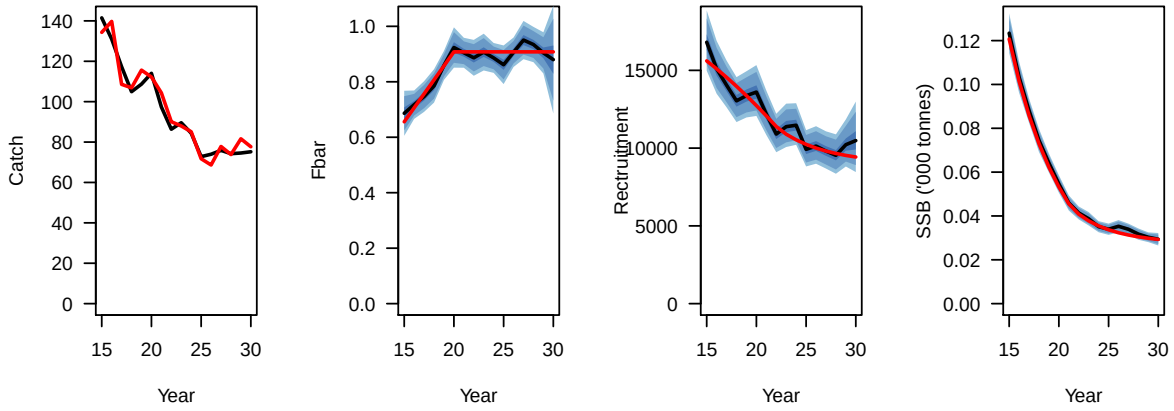


Figure 93: Model residuals. Colors represent ages

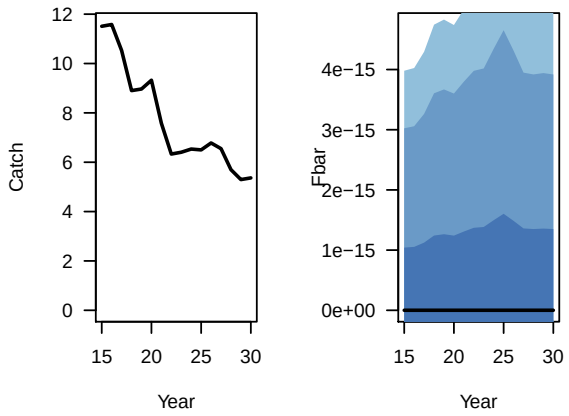


Figure 94: Model residuals. Colors represent ages

```
## Error:  need finite 'ylim' values
```

Stable at high exploitation

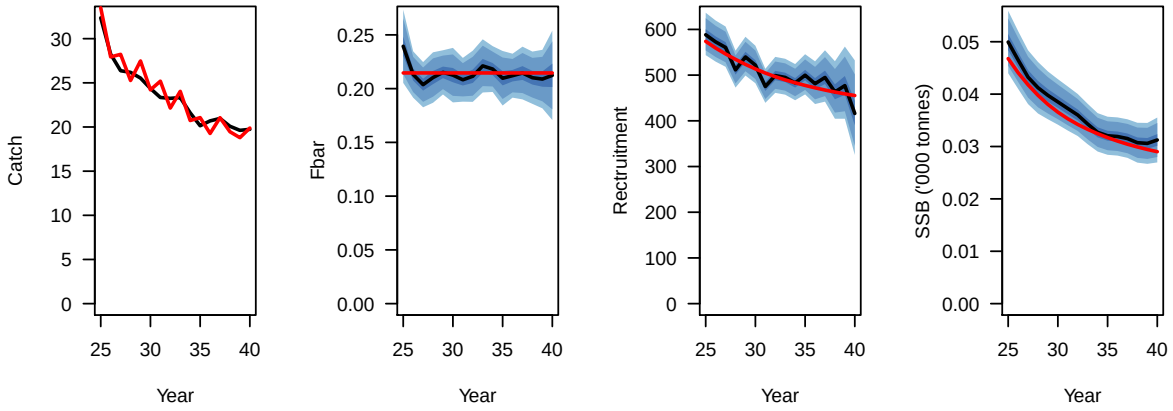


Figure 95: Model residuals. Colors represent ages

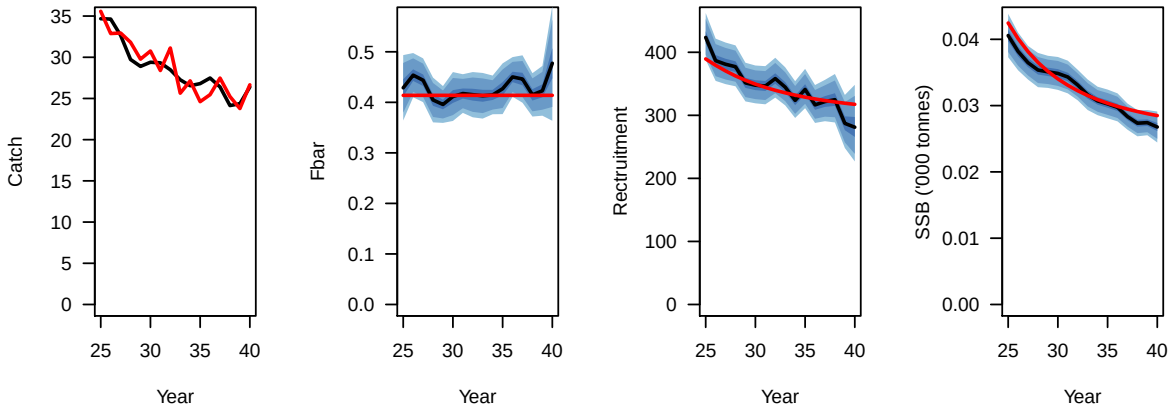


Figure 96: Model residuals. Colors represent ages

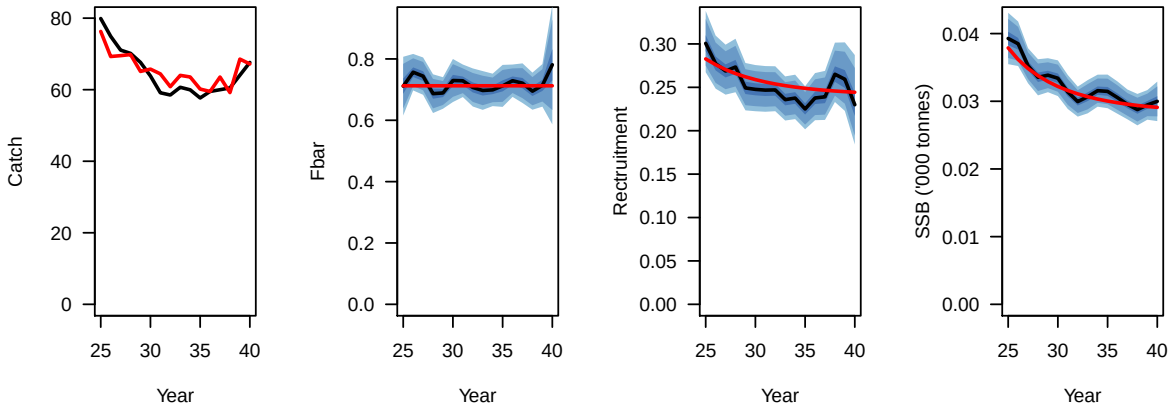


Figure 97: Model residuals. Colors represent ages

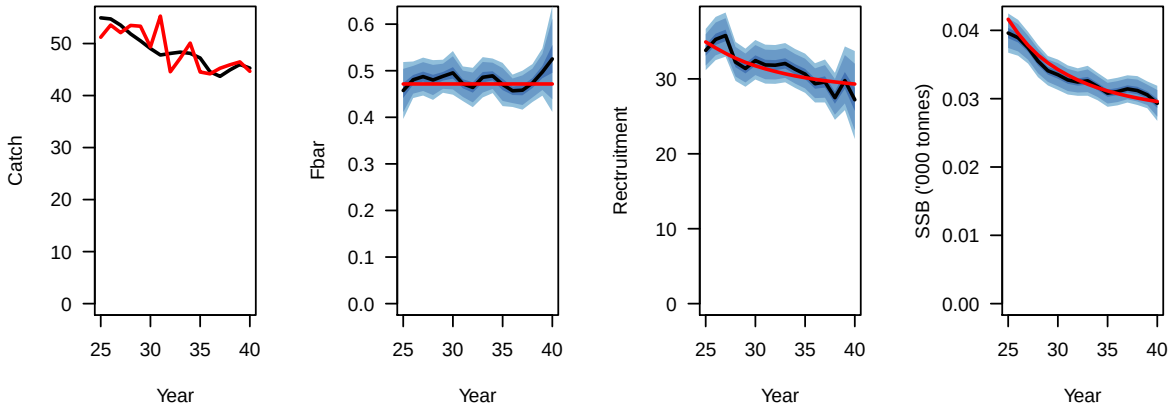


Figure 98: Model residuals. Colors represent ages

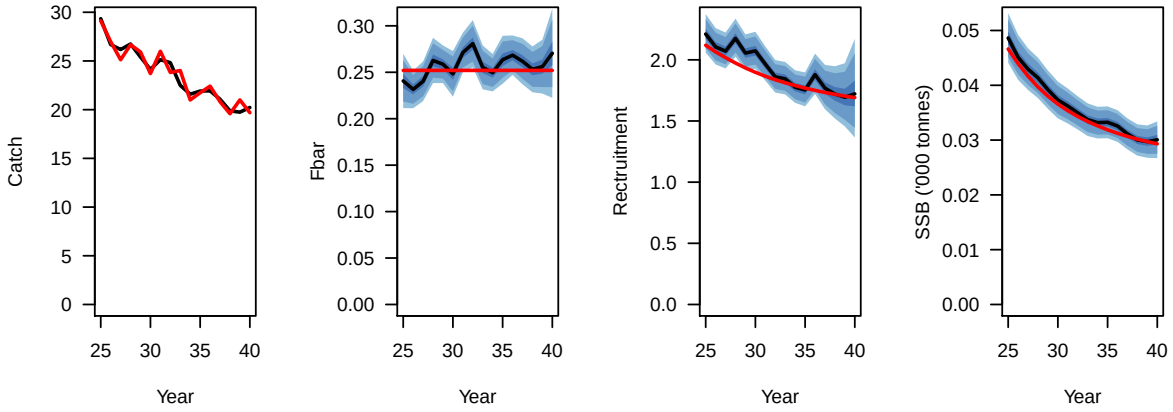


Figure 99: Model residuals. Colors represent ages

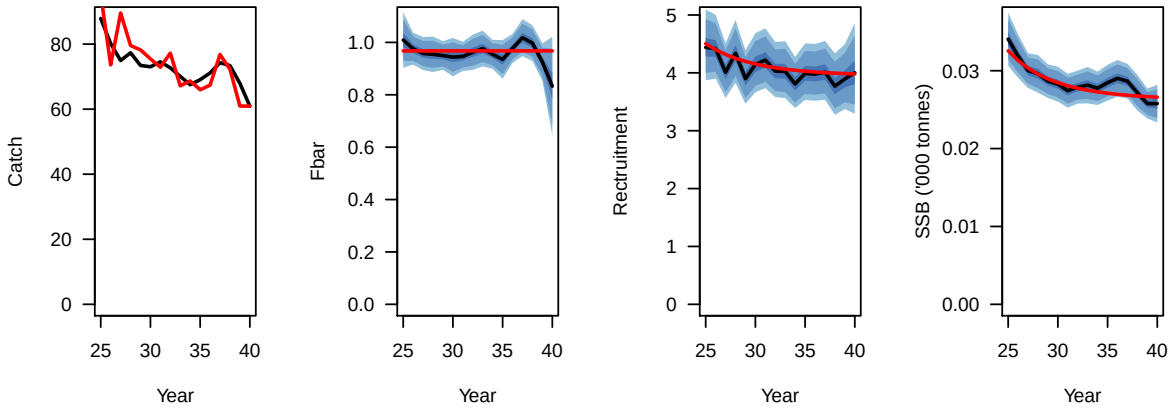


Figure 100: Model residuals. Colors represent ages

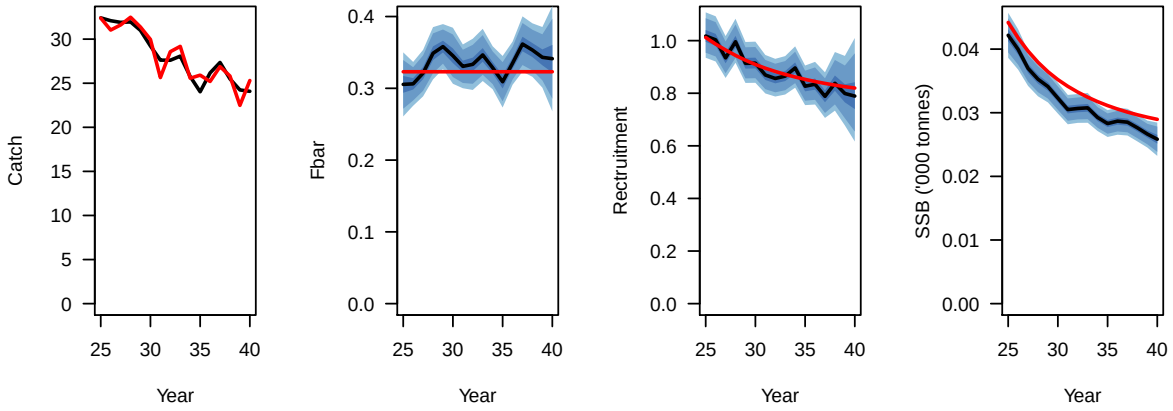


Figure 101: Model residuals. Colors represent ages

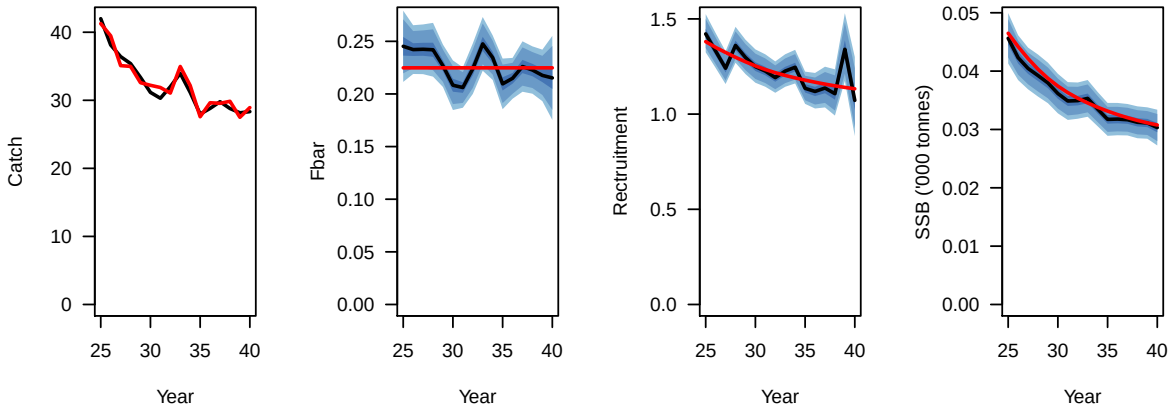


Figure 102: Model residuals. Colors represent ages

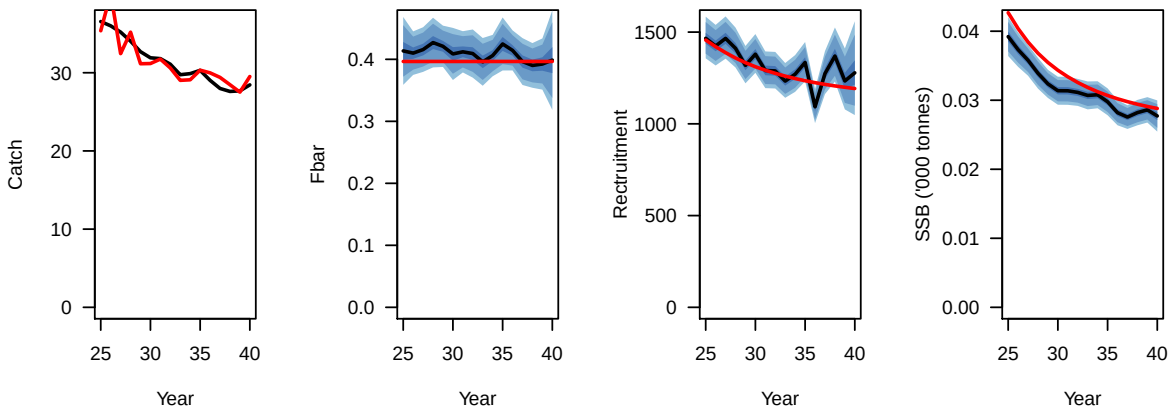


Figure 103: Model residuals. Colors represent ages

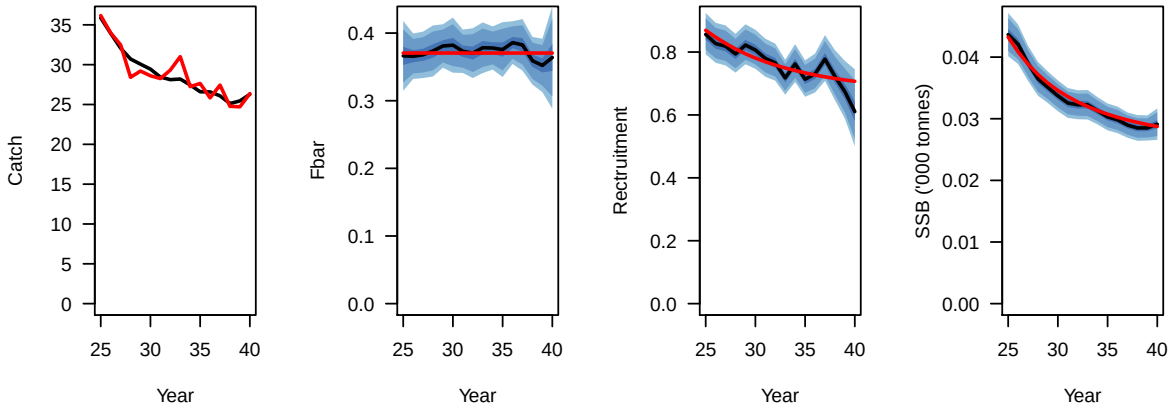


Figure 104: Model residuals. Colors represent ages

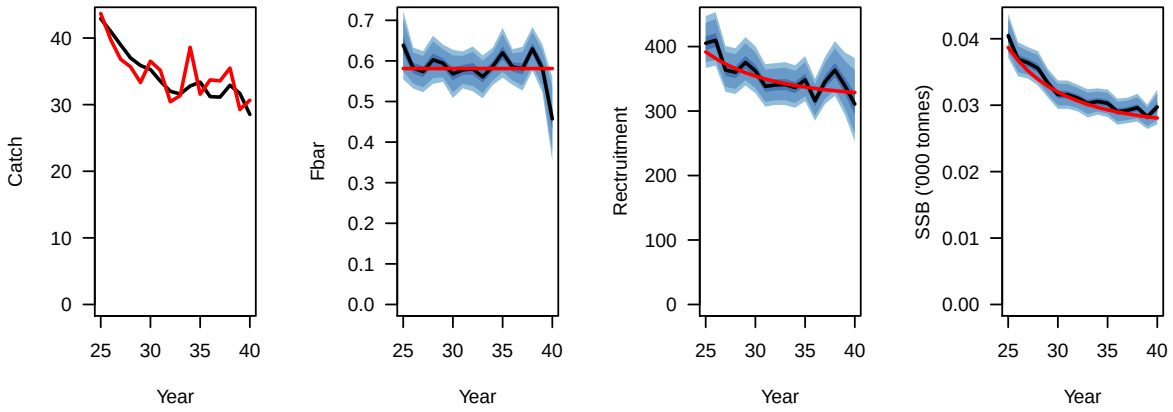


Figure 105: Model residuals. Colors represent ages

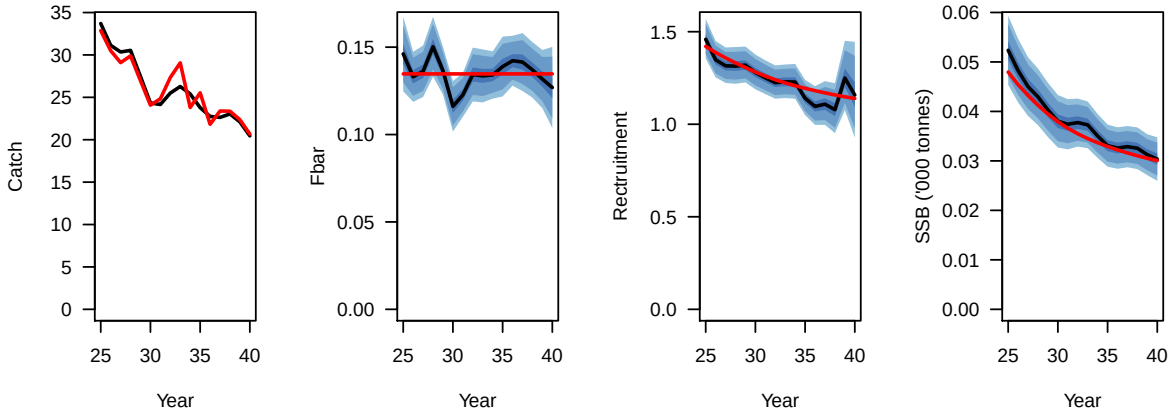


Figure 106: Model residuals. Colors represent ages

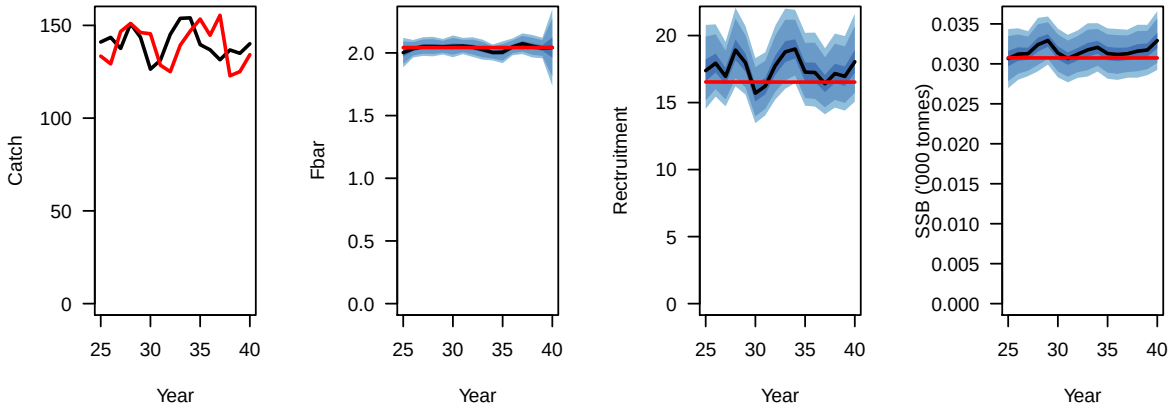


Figure 107: Model residuals. Colors represent ages

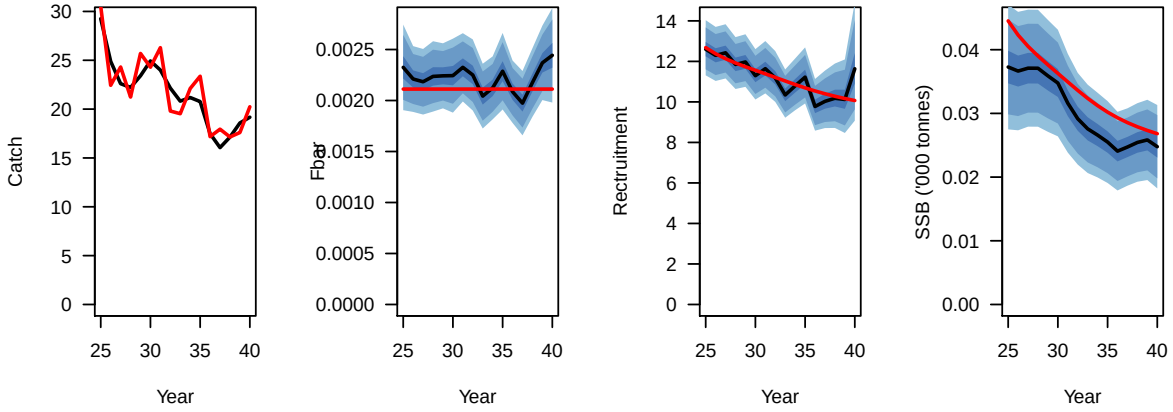


Figure 108: Model residuals. Colors represent ages

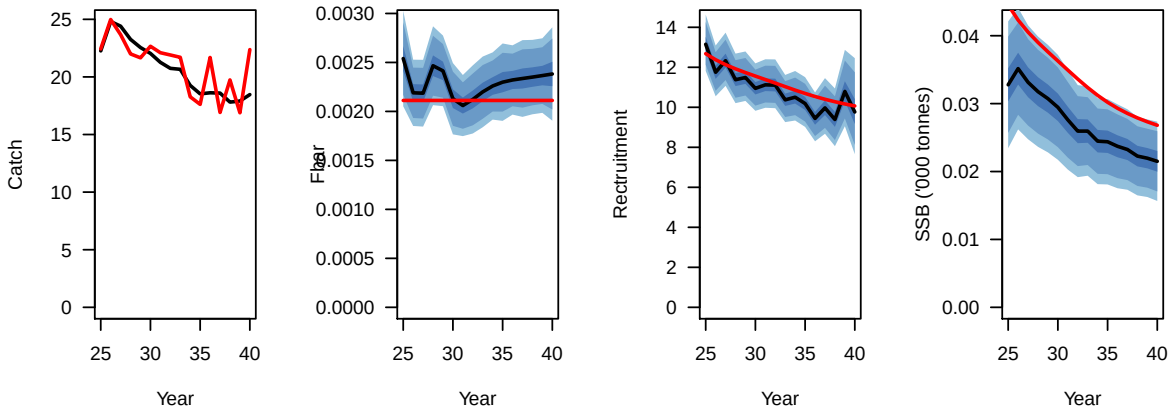


Figure 109: Model residuals. Colors represent ages

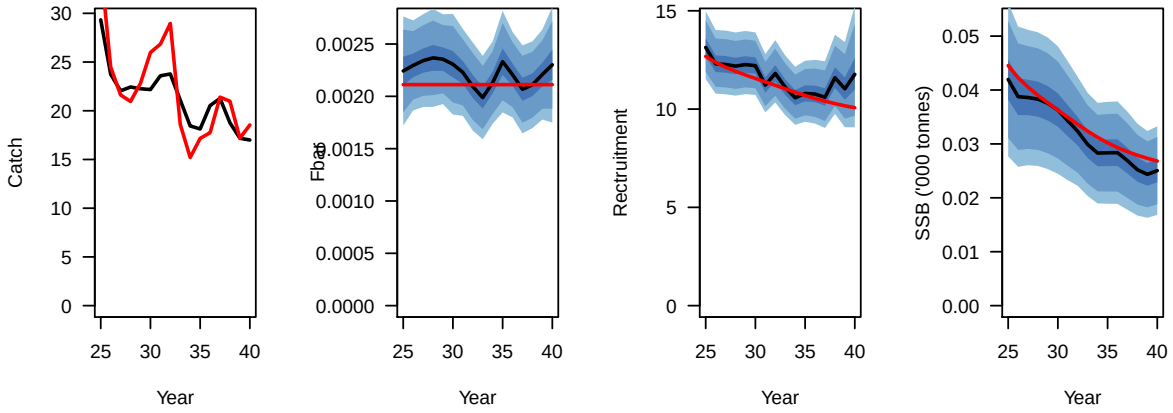


Figure 110: Model residuals. Colors represent ages

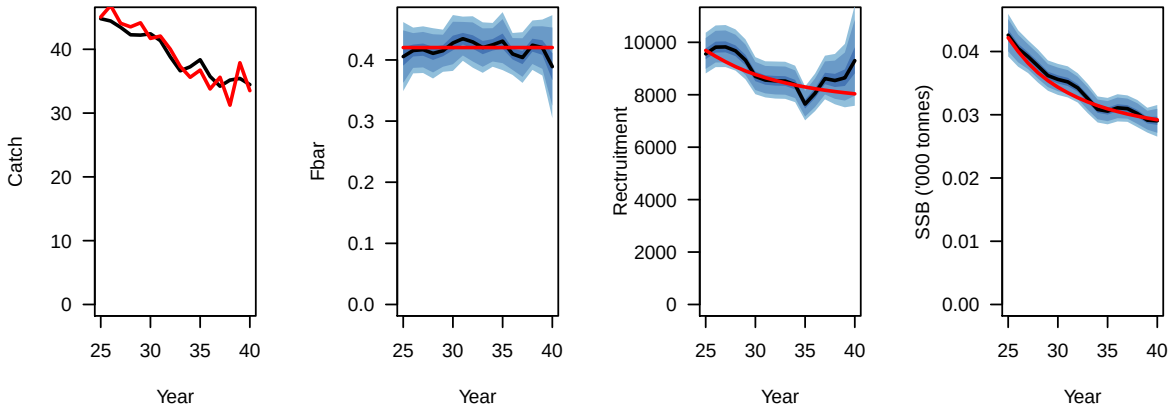


Figure 111: Model residuals. Colors represent ages

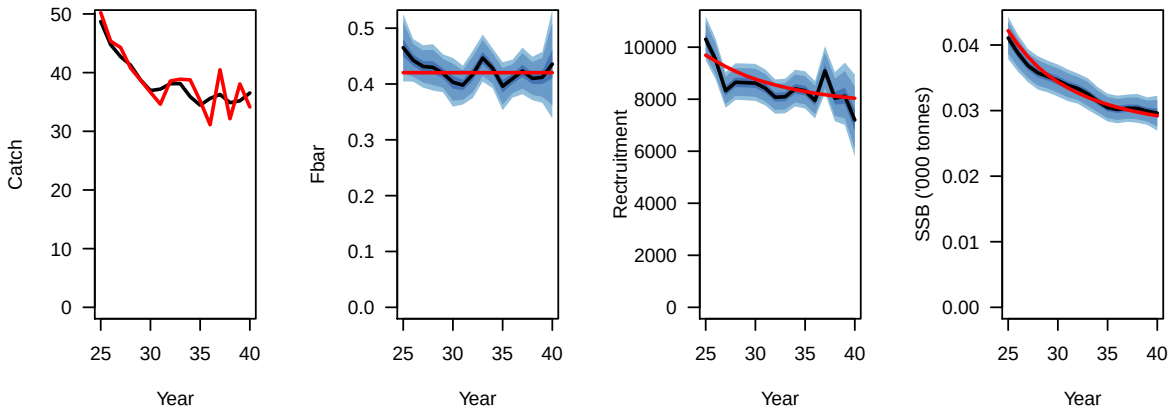


Figure 112: Model residuals. Colors represent ages

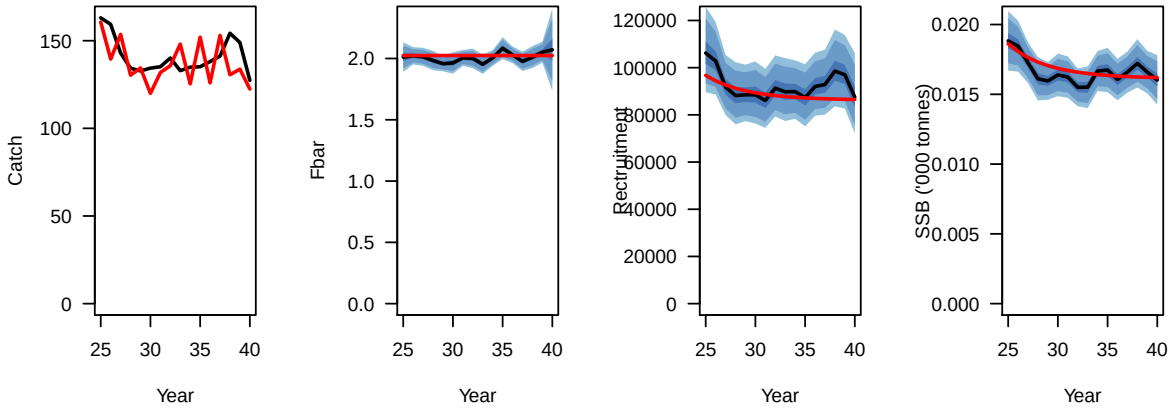


Figure 113: Model residuals. Colors represent ages

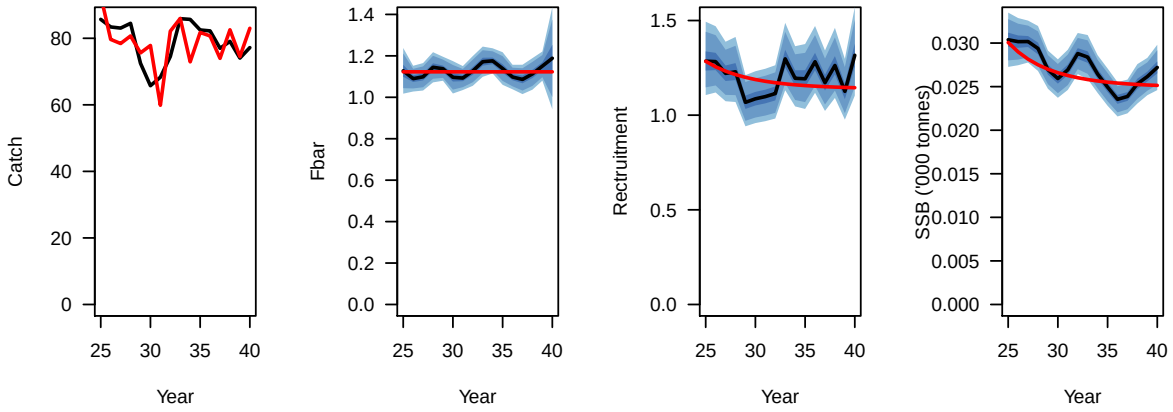


Figure 114: Model residuals. Colors represent ages

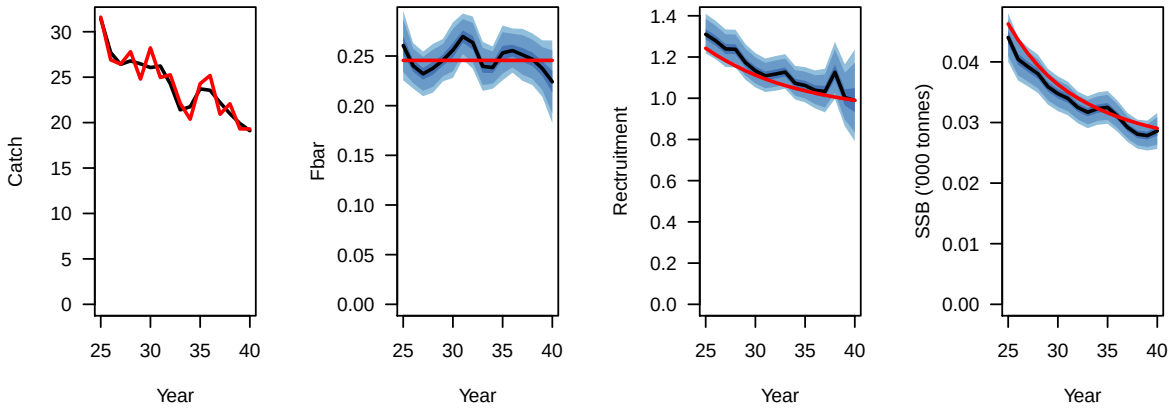


Figure 115: Model residuals. Colors represent ages

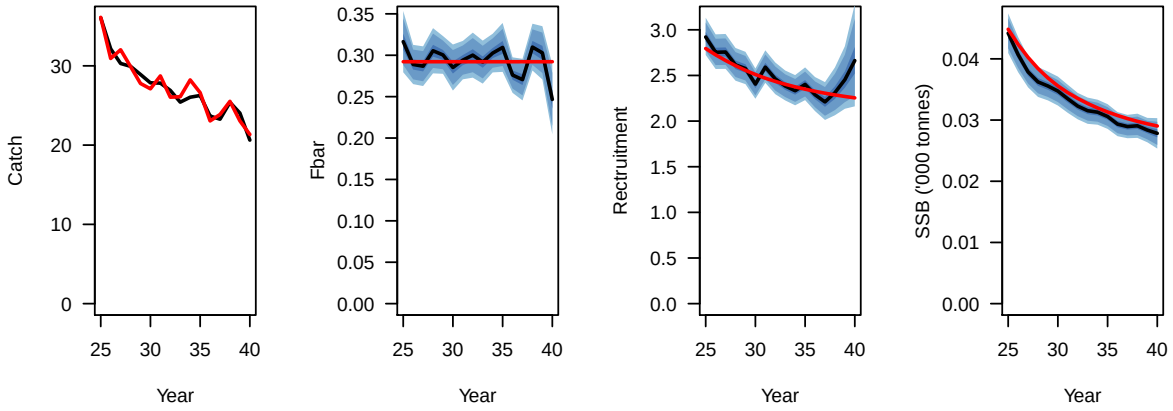


Figure 116: Model residuals. Colors represent ages

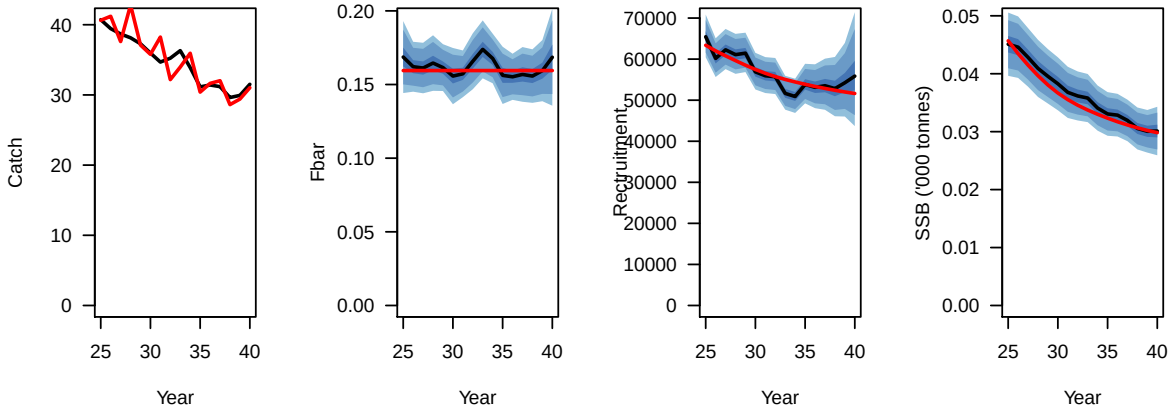


Figure 117: Model residuals. Colors represent ages

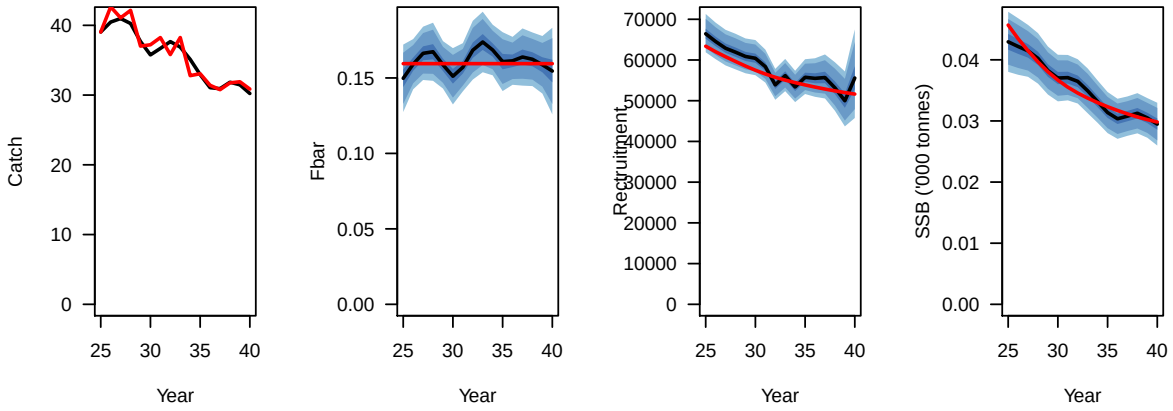


Figure 118: Model residuals. Colors represent ages

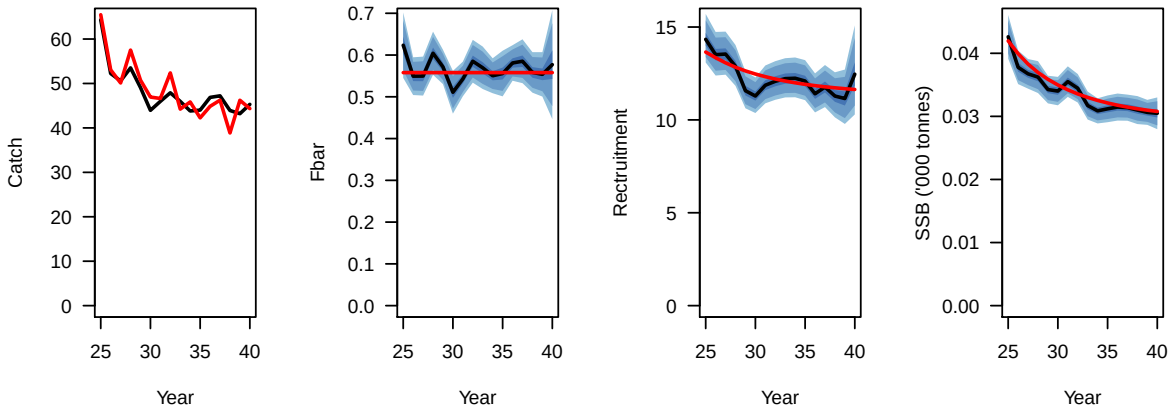


Figure 119: Model residuals. Colors represent ages

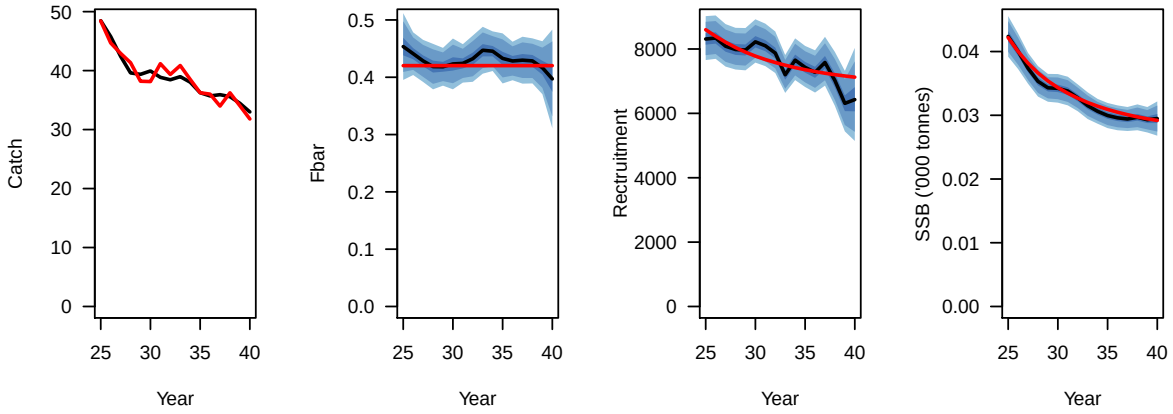


Figure 120: Model residuals. Colors represent ages

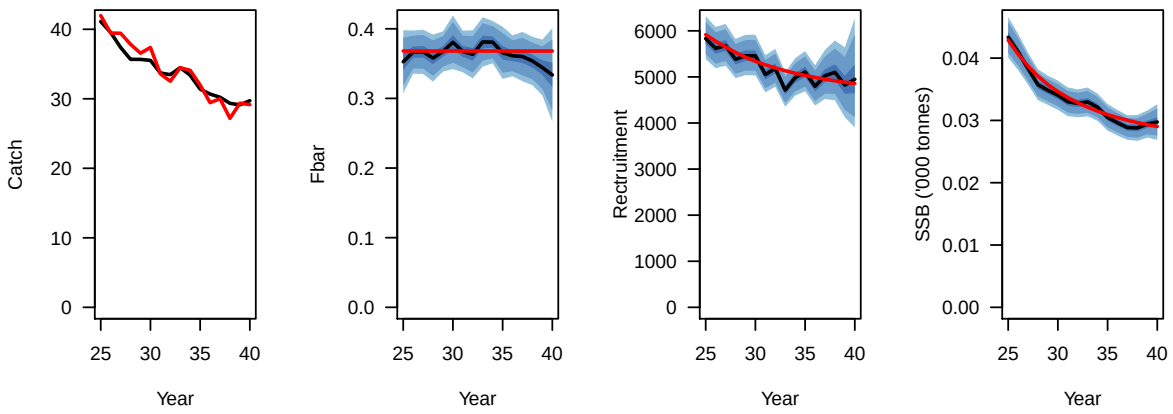


Figure 121: Model residuals. Colors represent ages

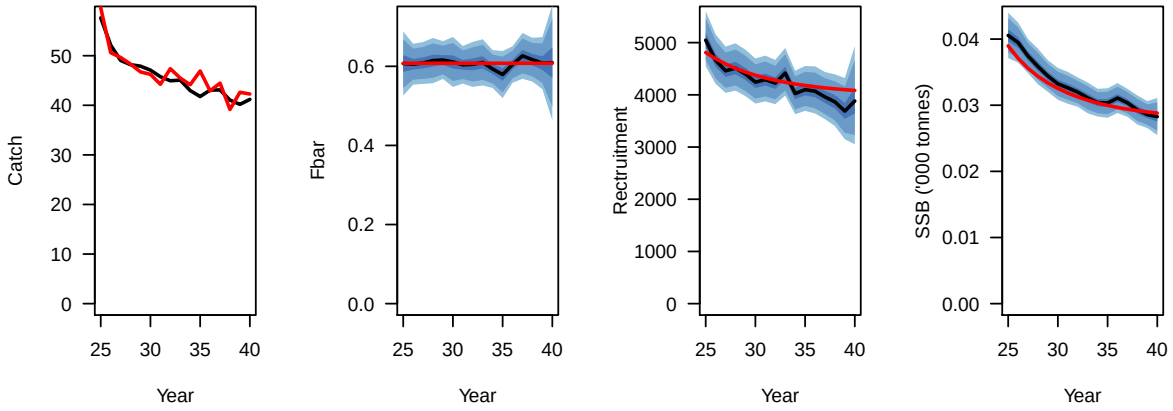


Figure 122: Model residuals. Colors represent ages

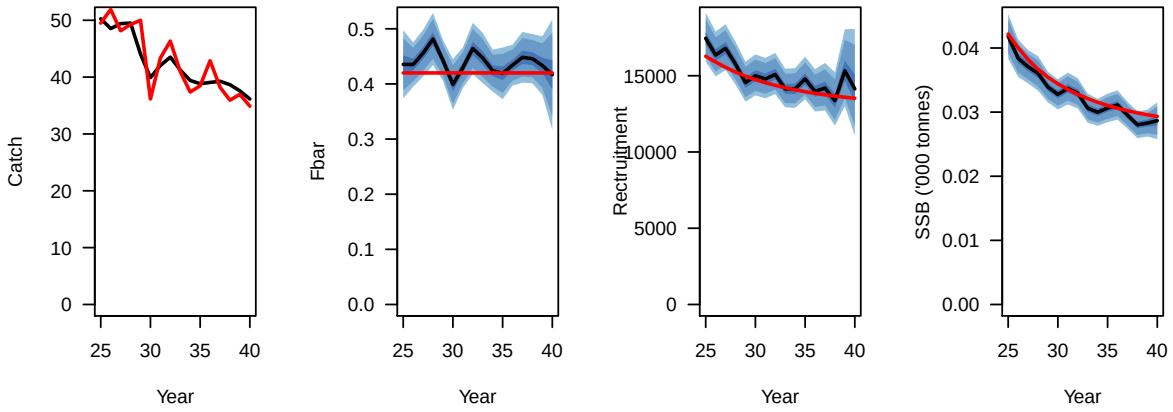


Figure 123: Model residuals. Colors represent ages

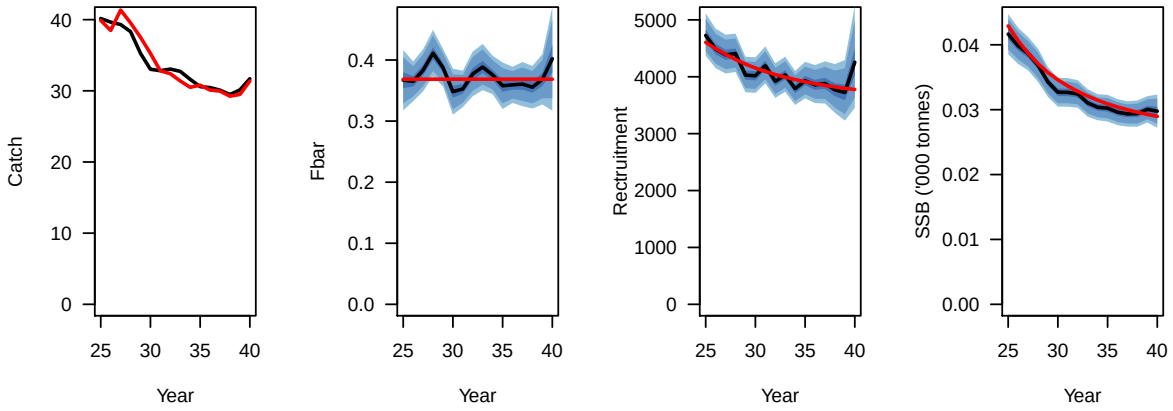


Figure 124: Model residuals. Colors represent ages

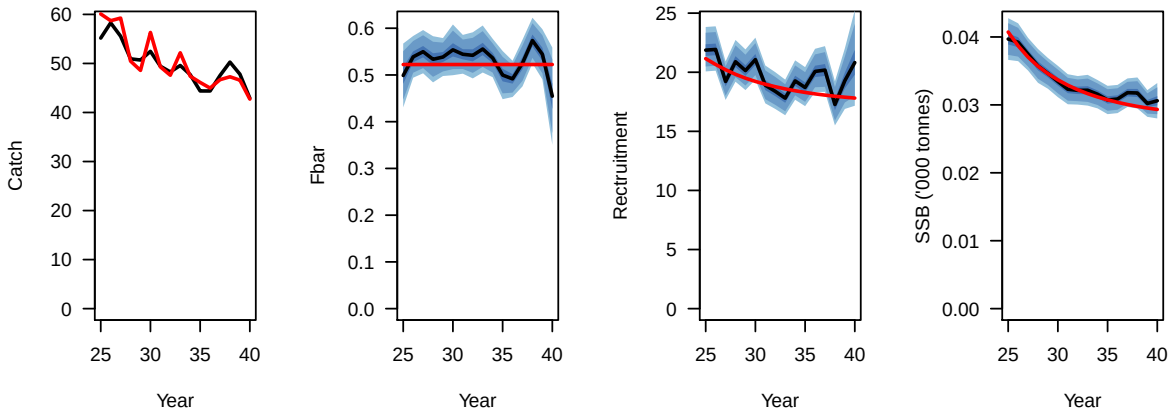


Figure 125: Model residuals. Colors represent ages

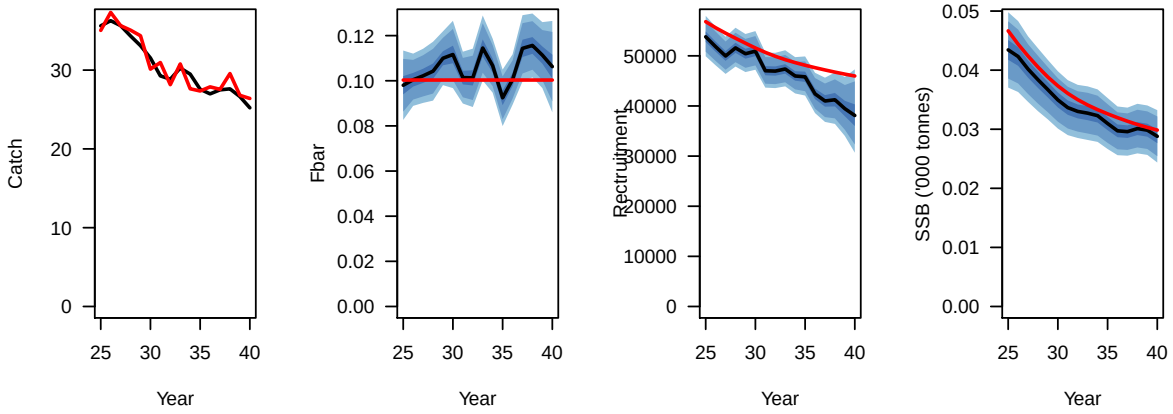


Figure 126: Model residuals. Colors represent ages

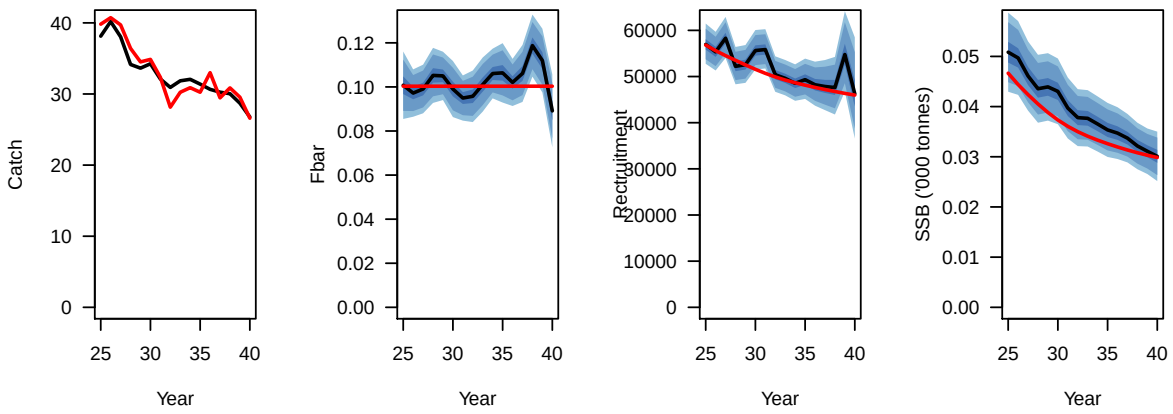


Figure 127: Model residuals. Colors represent ages

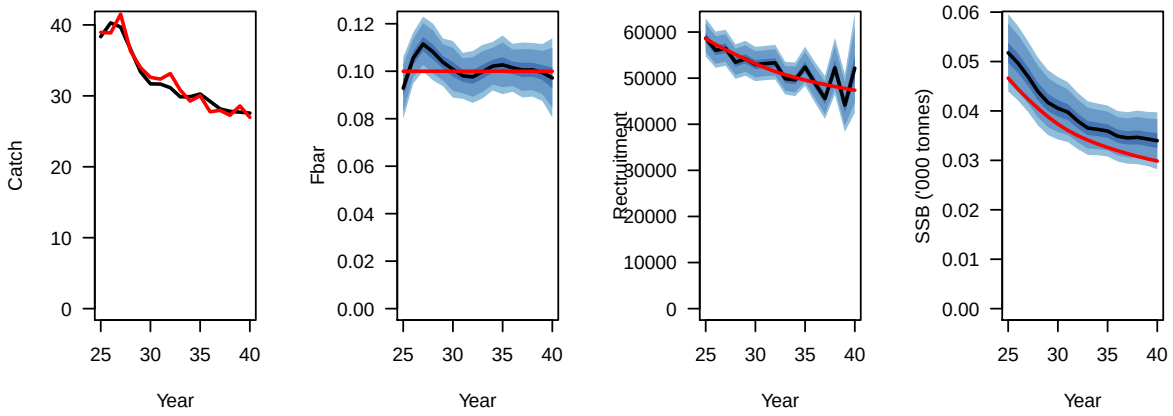


Figure 128: Model residuals. Colors represent ages

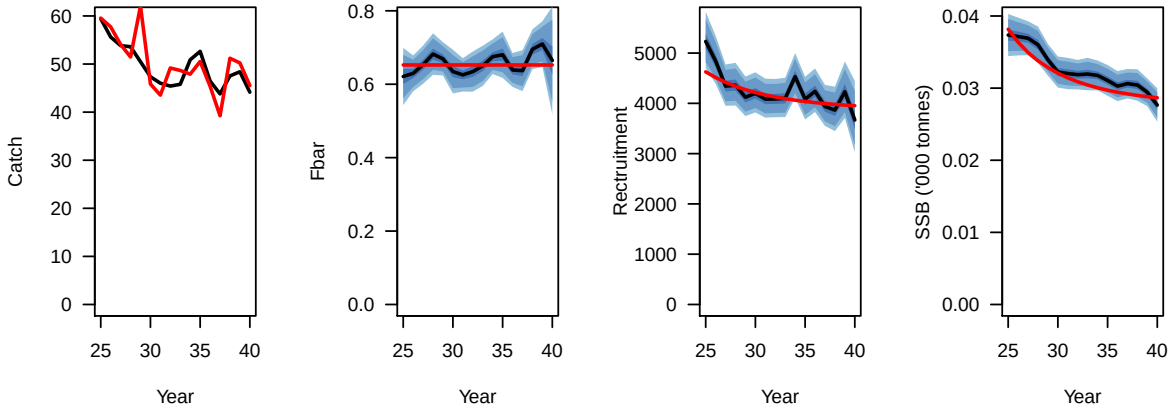


Figure 129: Model residuals. Colors represent ages

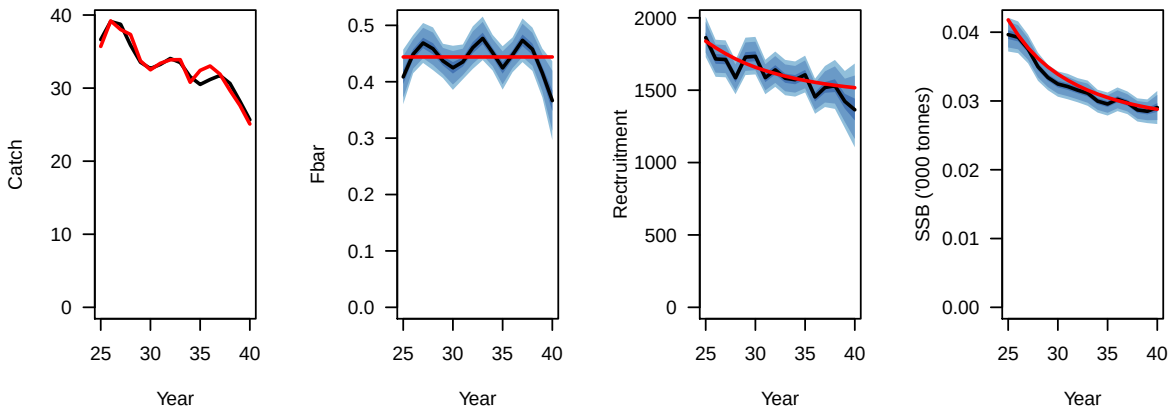


Figure 130: Model residuals. Colors represent ages

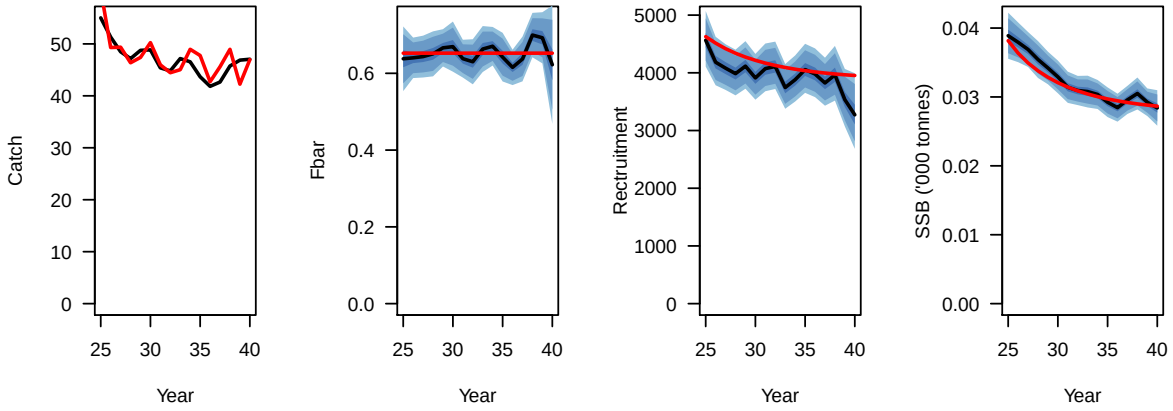


Figure 131: Model residuals. Colors represent ages

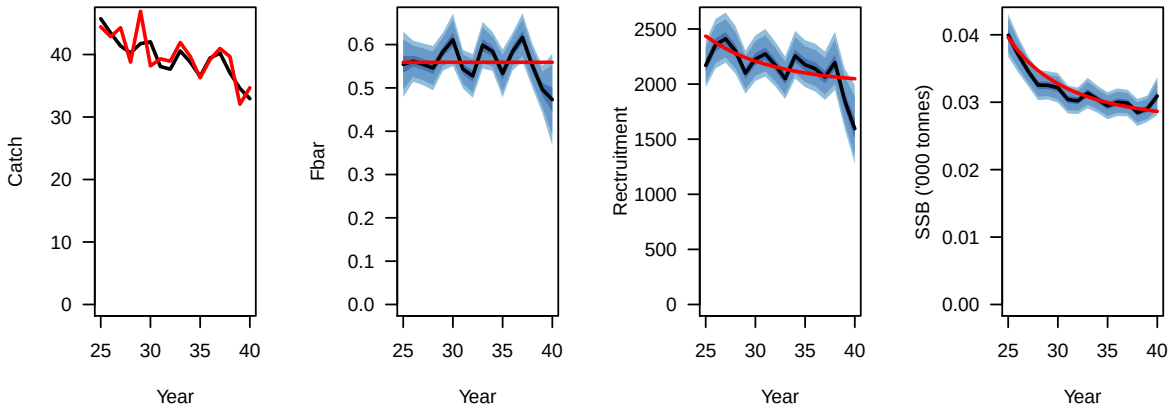


Figure 132: Model residuals. Colors represent ages

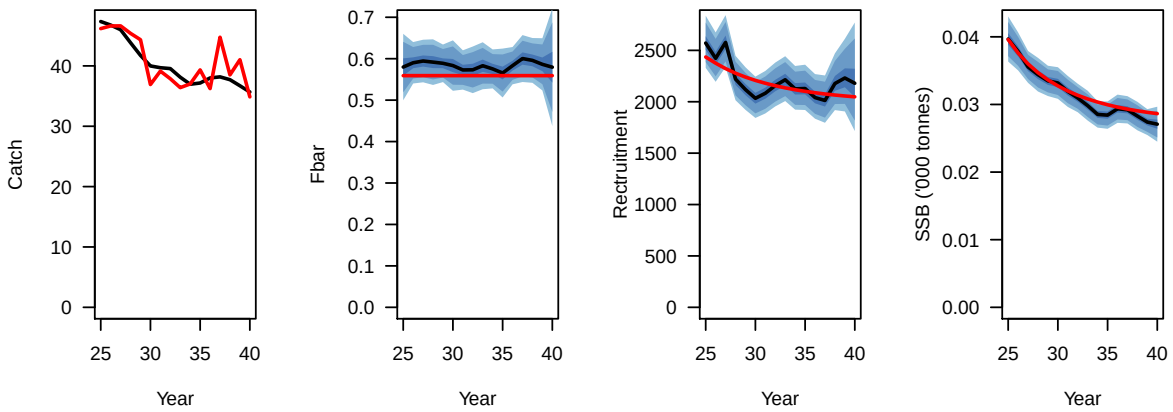


Figure 133: Model residuals. Colors represent ages

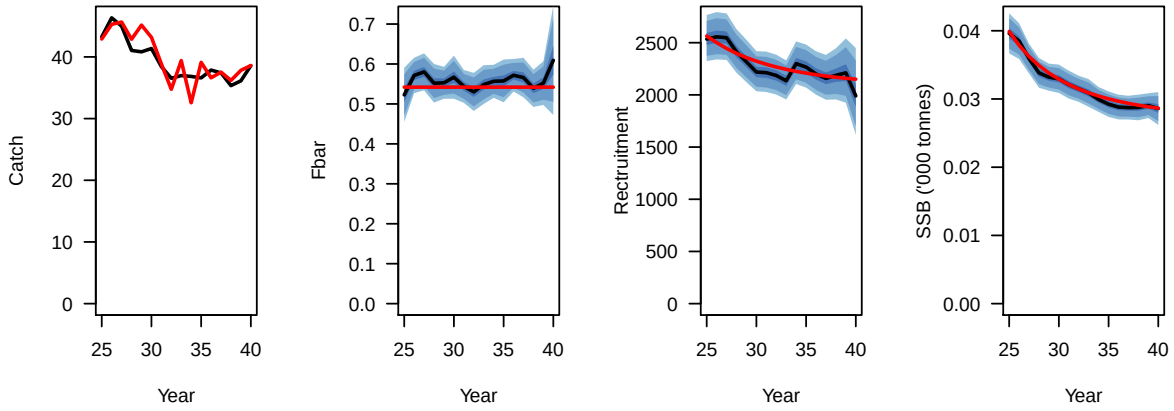


Figure 134: Model residuals. Colors represent ages

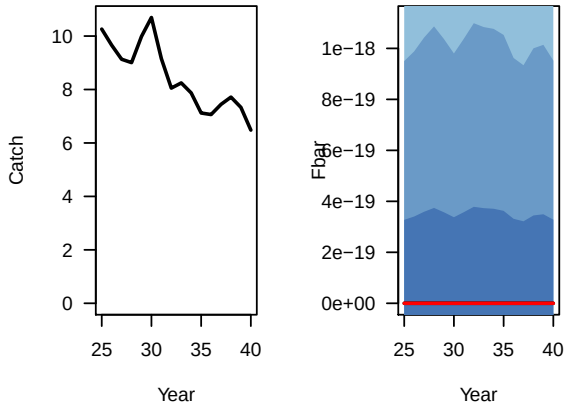


Figure 135: Model residuals. Colors represent ages

```
## Error:  need finite 'ylim' values
```

Recovery

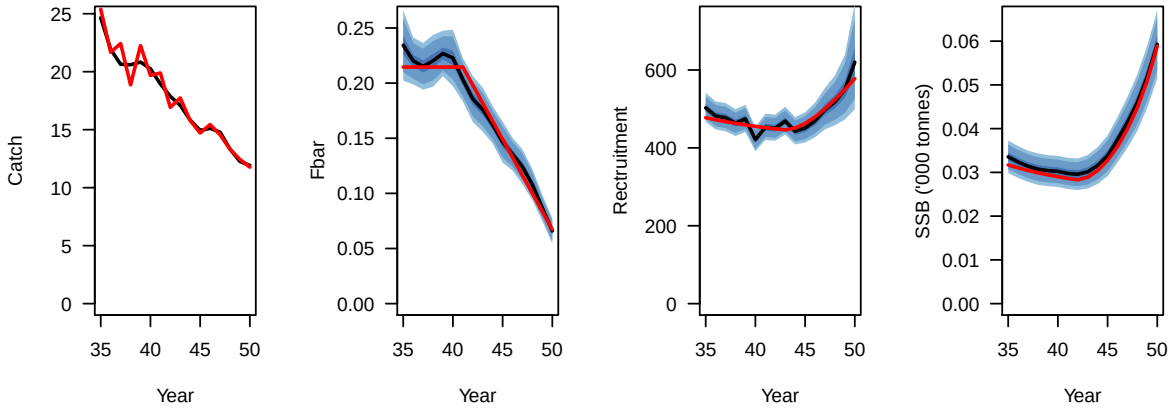


Figure 136: Model residuals. Colors represent ages

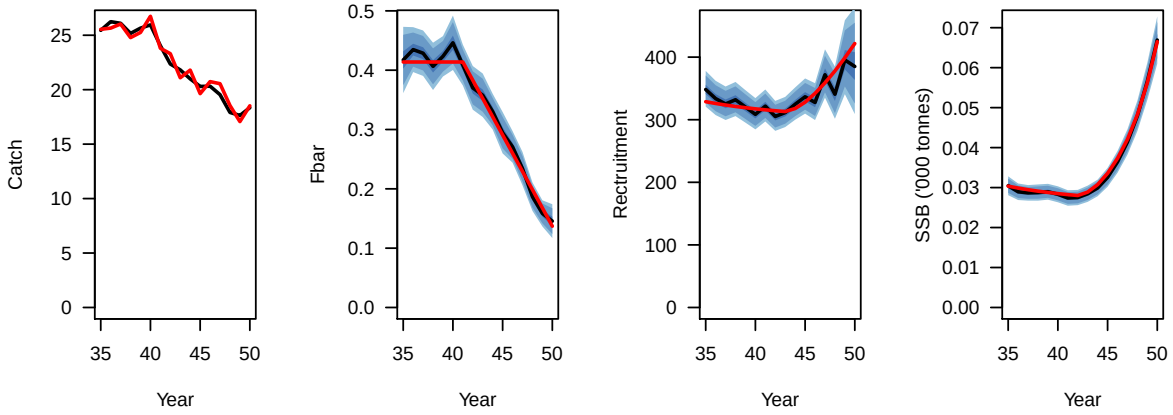


Figure 137: Model residuals. Colors represent ages

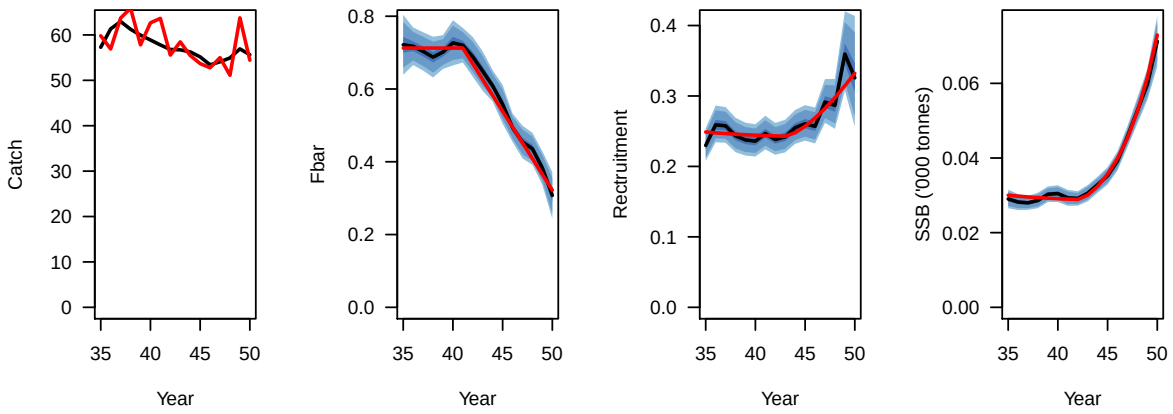


Figure 138: Model residuals. Colors represent ages

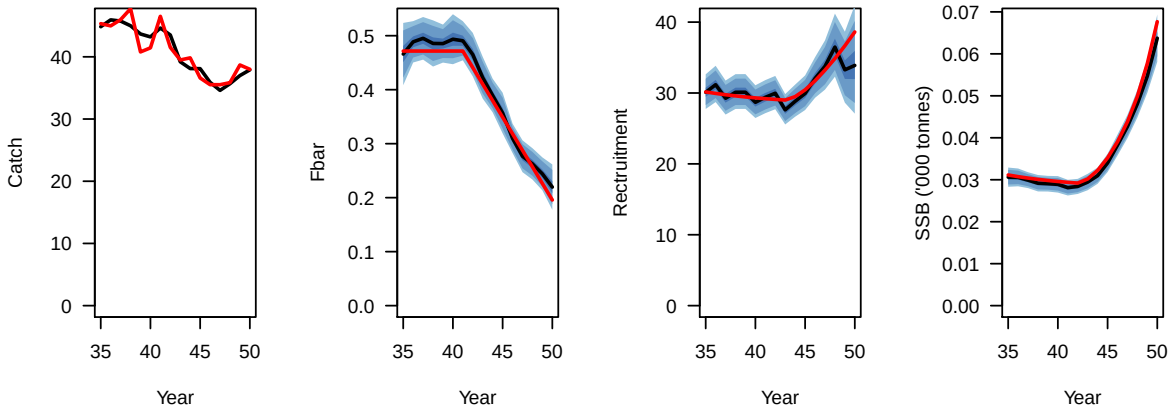


Figure 139: Model residuals. Colors represent ages

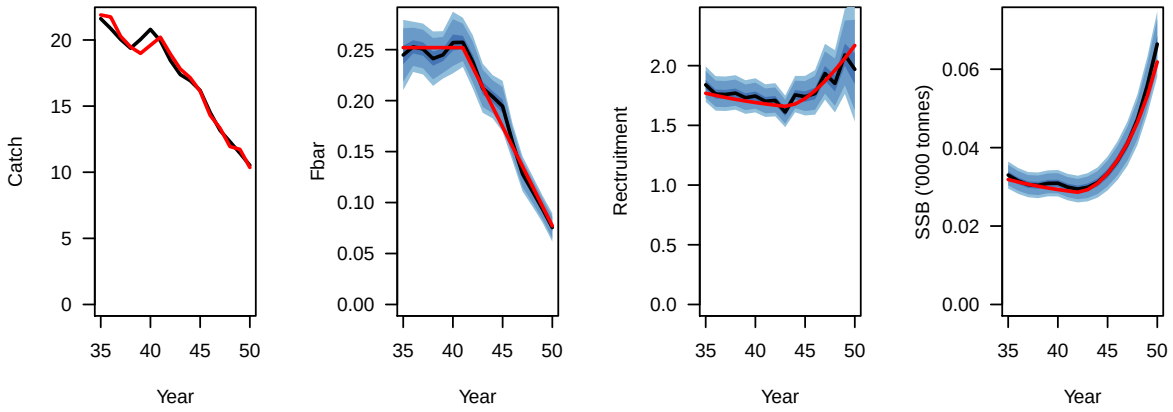


Figure 140: Model residuals. Colors represent ages

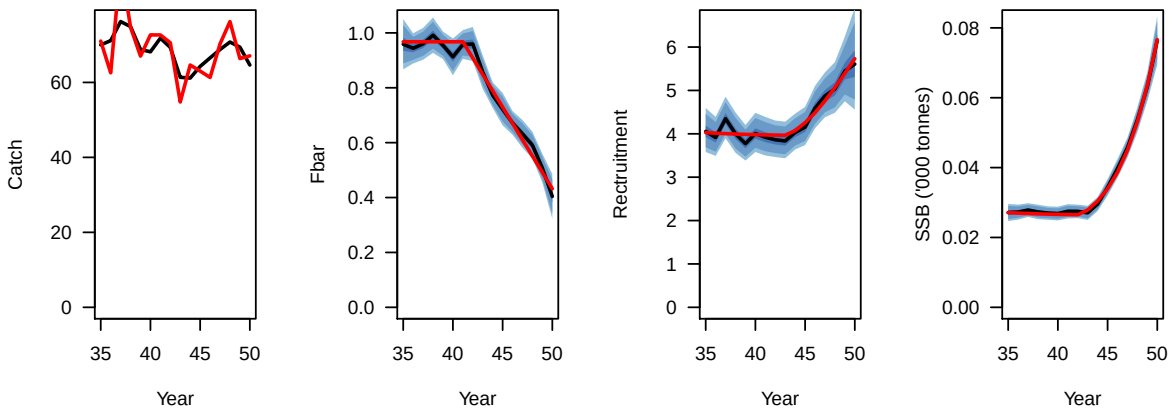


Figure 141: Model residuals. Colors represent ages

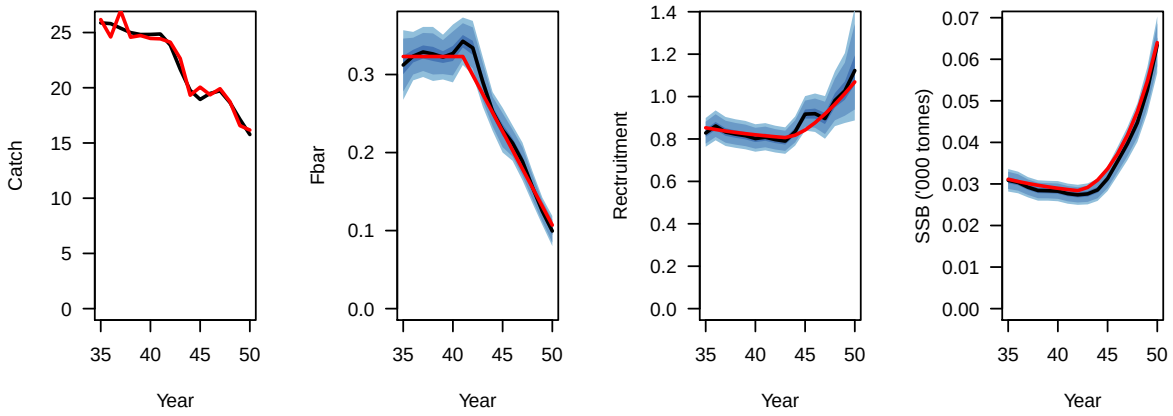


Figure 142: Model residuals. Colors represent ages

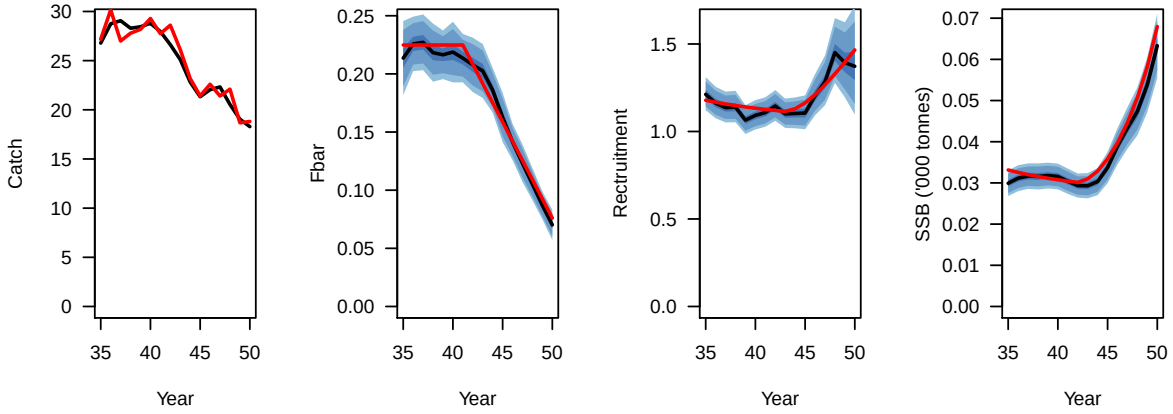


Figure 143: Model residuals. Colors represent ages

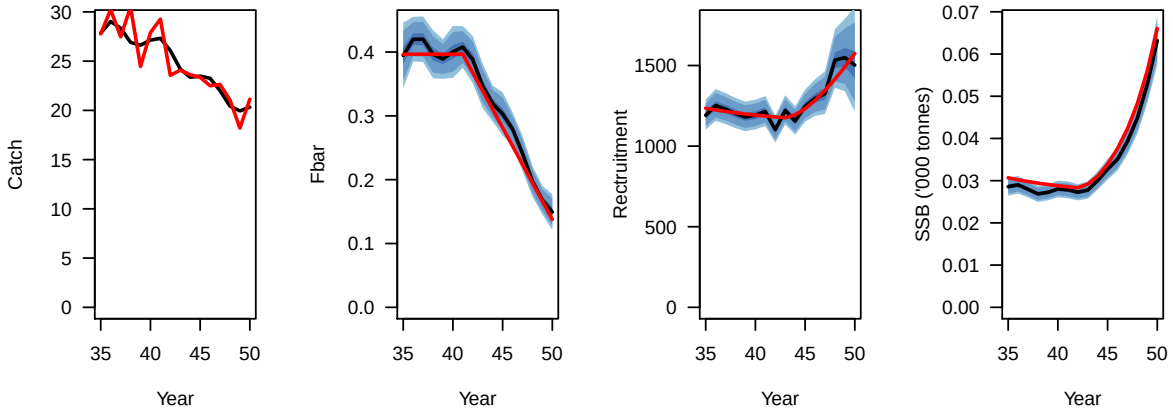


Figure 144: Model residuals. Colors represent ages

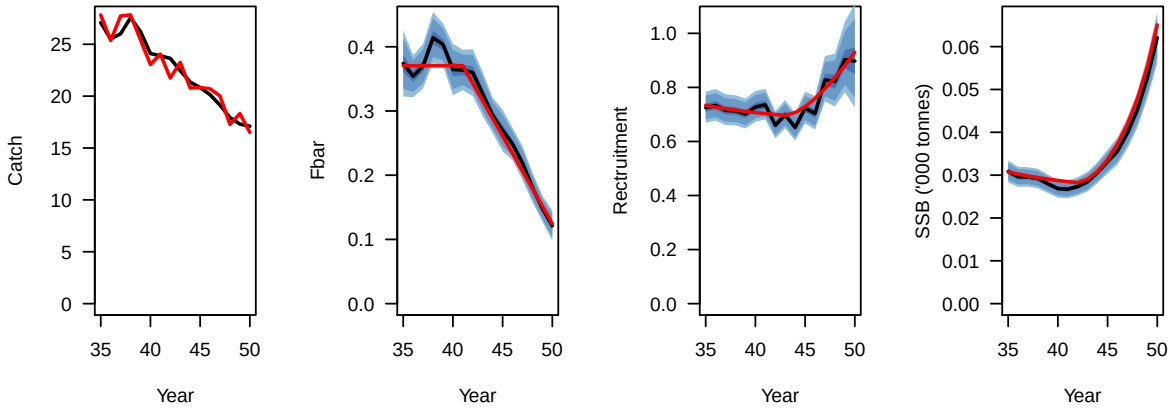


Figure 145: Model residuals. Colors represent ages

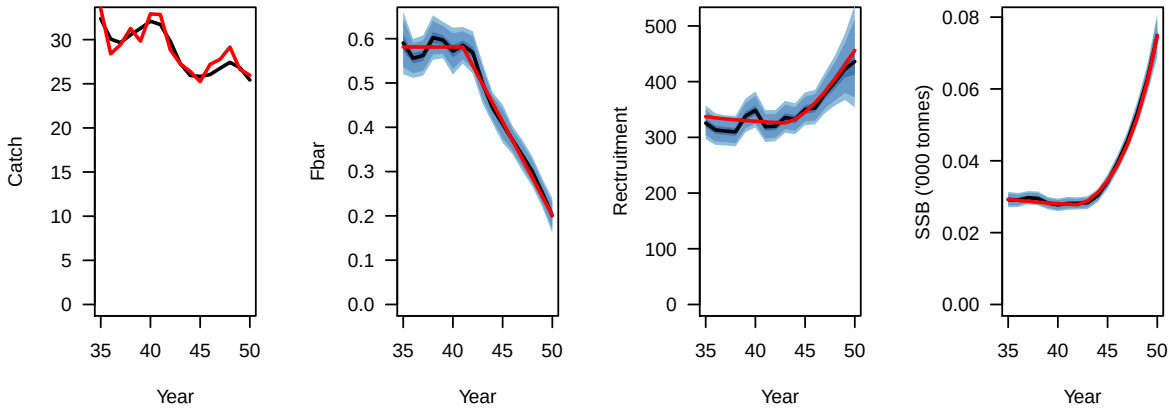


Figure 146: Model residuals. Colors represent ages

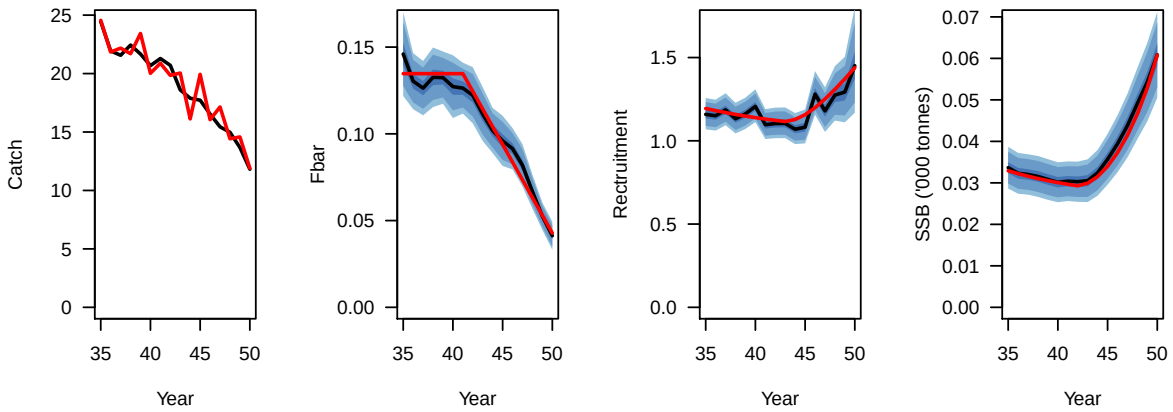


Figure 147: Model residuals. Colors represent ages

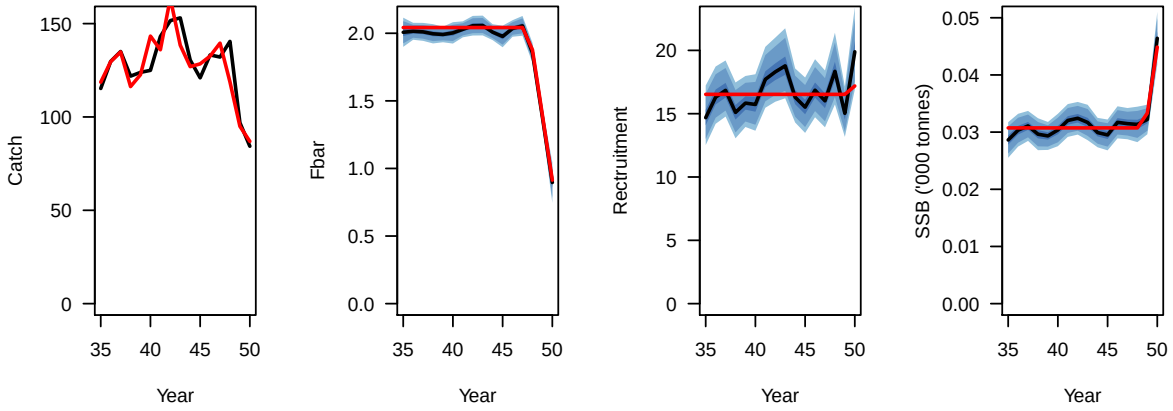


Figure 148: Model residuals. Colors represent ages

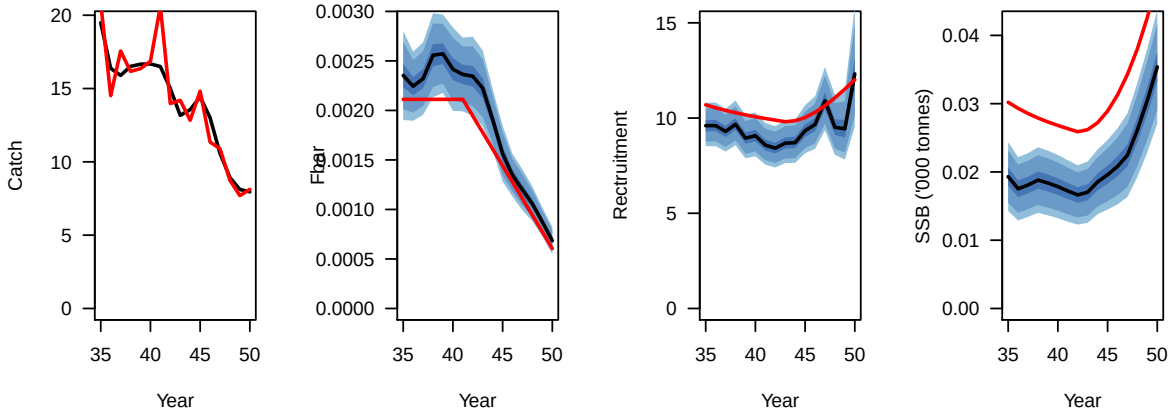


Figure 149: Model residuals. Colors represent ages

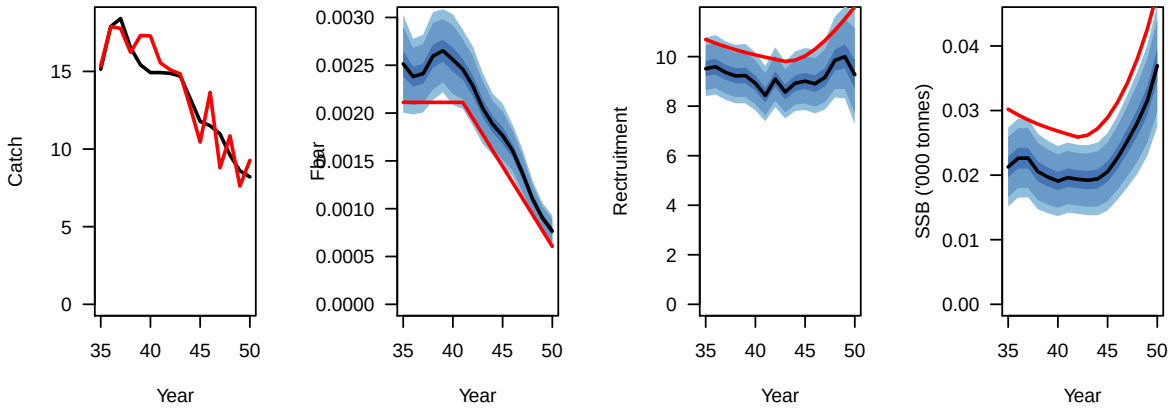


Figure 150: Model residuals. Colors represent ages

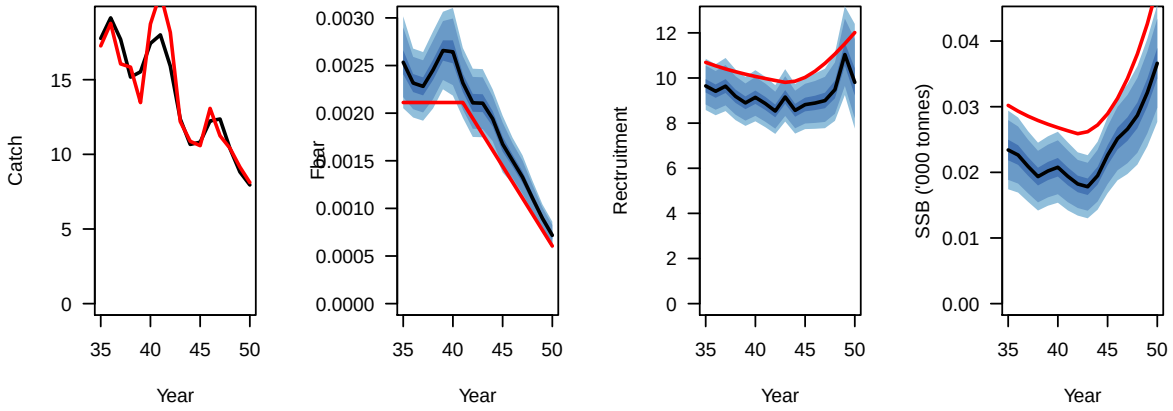


Figure 151: Model residuals. Colors represent ages

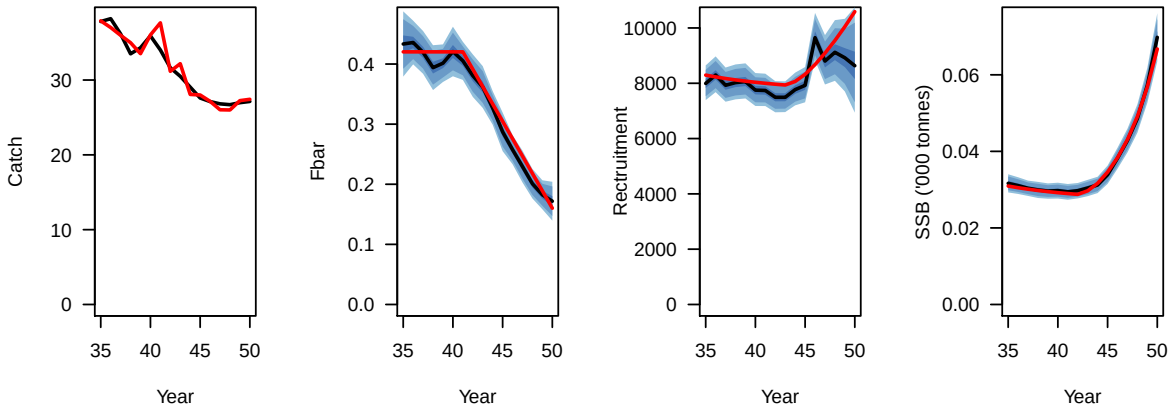


Figure 152: Model residuals. Colors represent ages

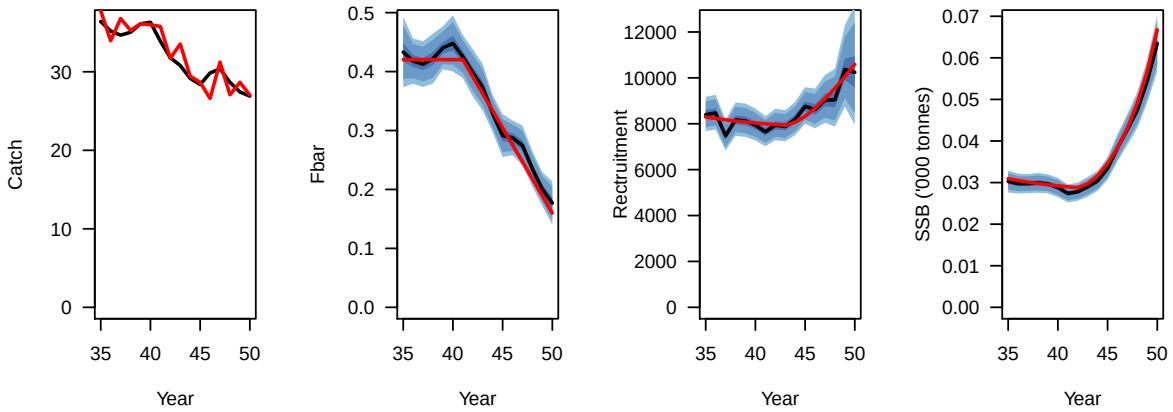


Figure 153: Model residuals. Colors represent ages

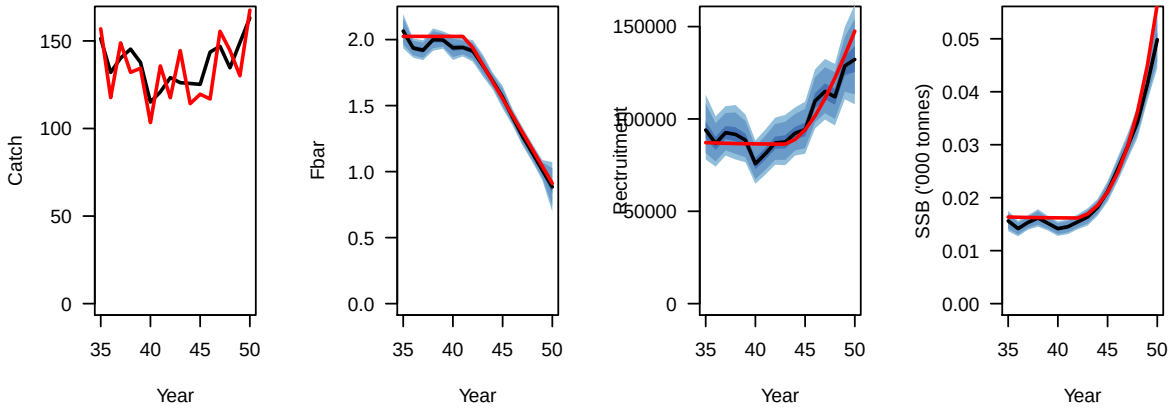


Figure 154: Model residuals. Colors represent ages

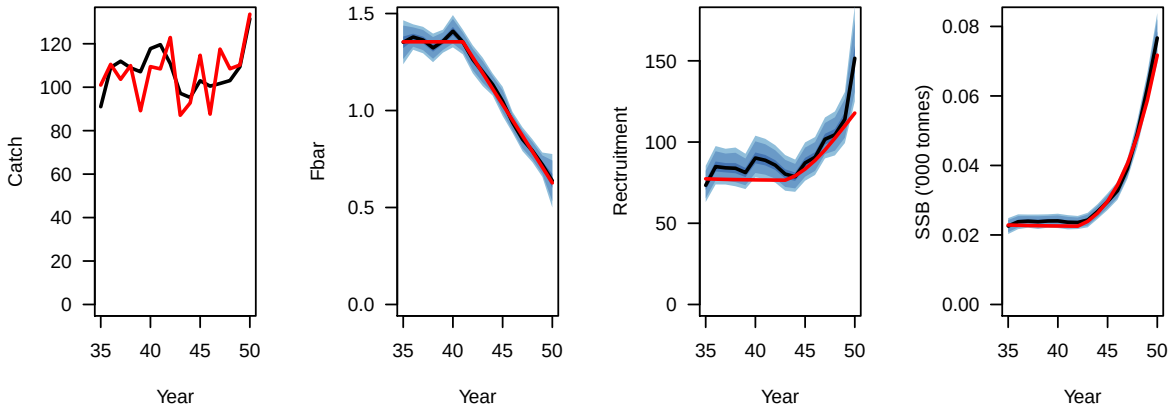
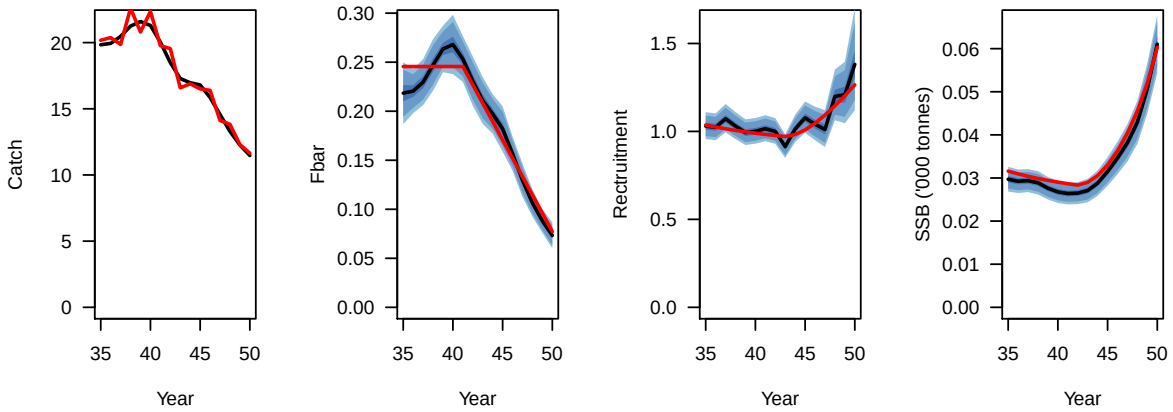


Figure 155: Model residuals. Colors represent ages



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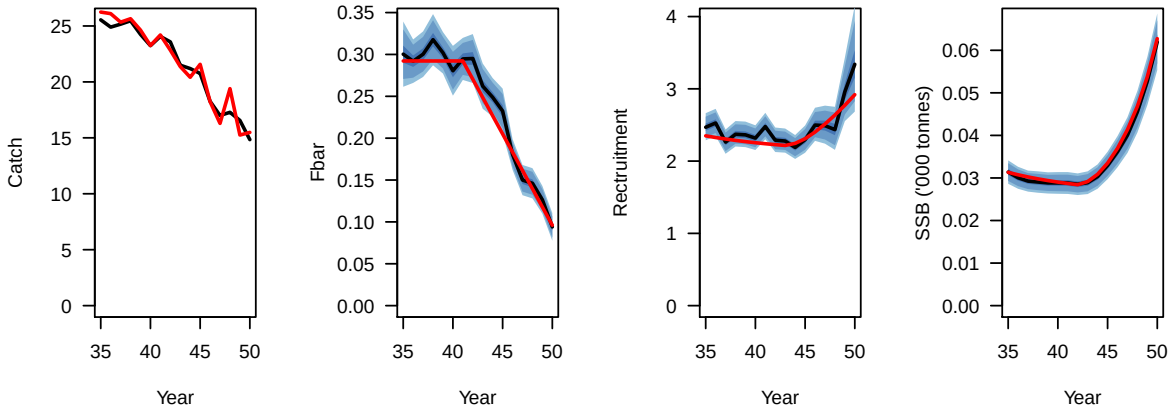


Figure 157: Model residuals. Colors represent ages

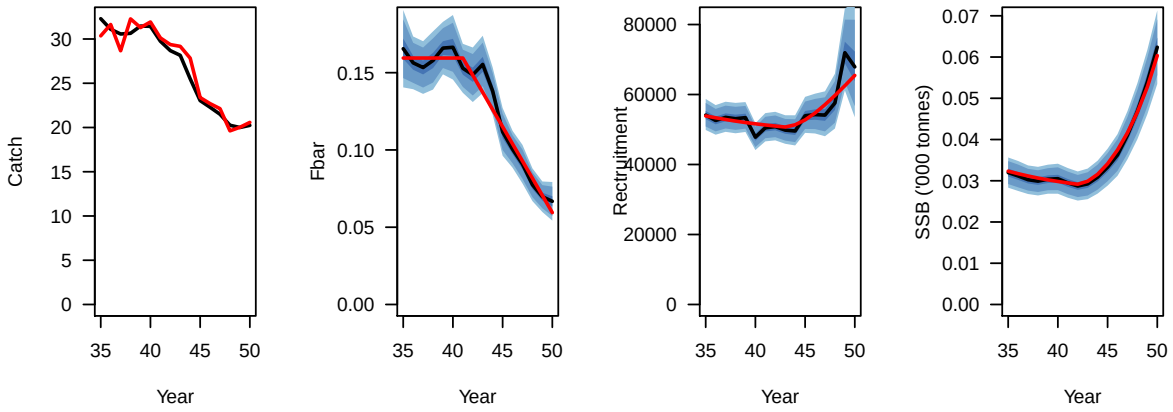


Figure 158: Model residuals. Colors represent ages

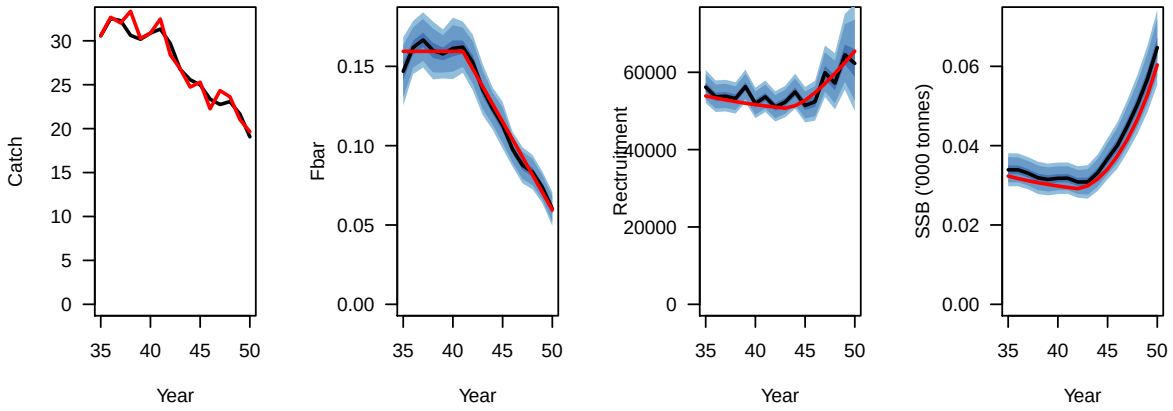


Figure 159: Model residuals. Colors represent ages

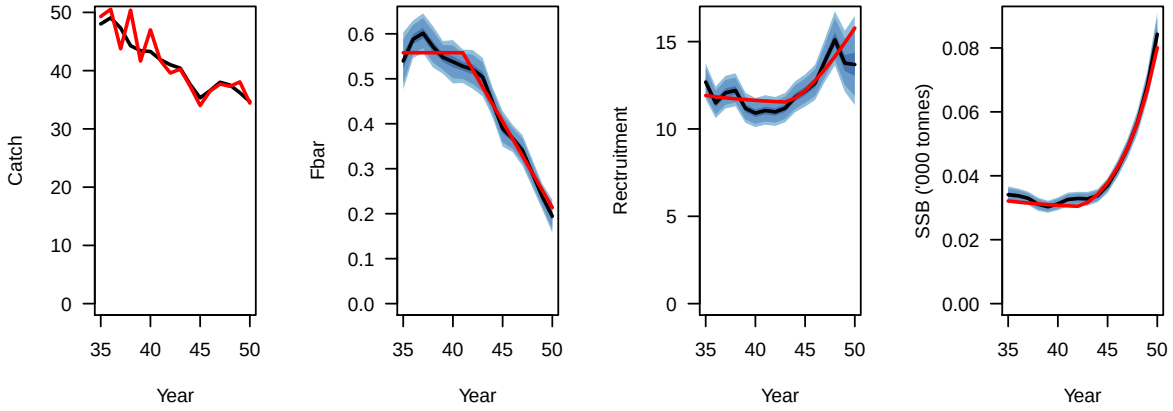


Figure 160: Model residuals. Colors represent ages

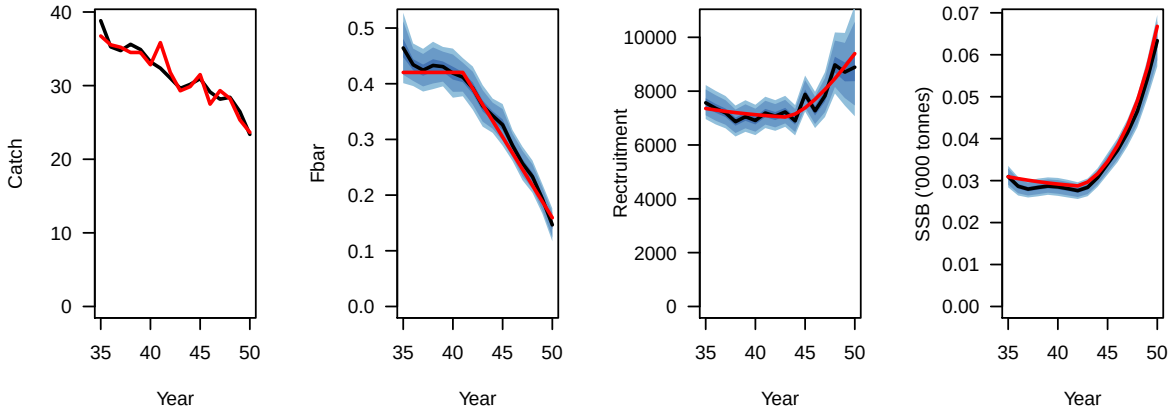


Figure 161: Model residuals. Colors represent ages

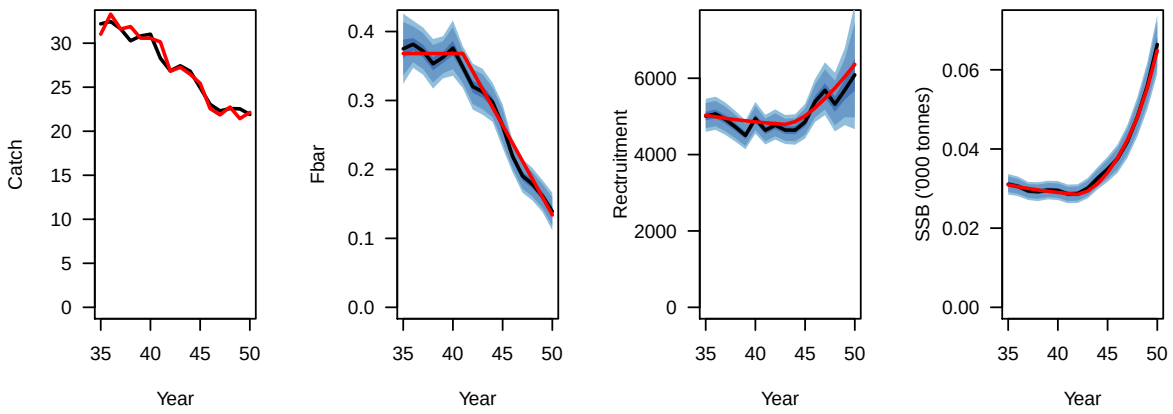


Figure 162: Model residuals. Colors represent ages

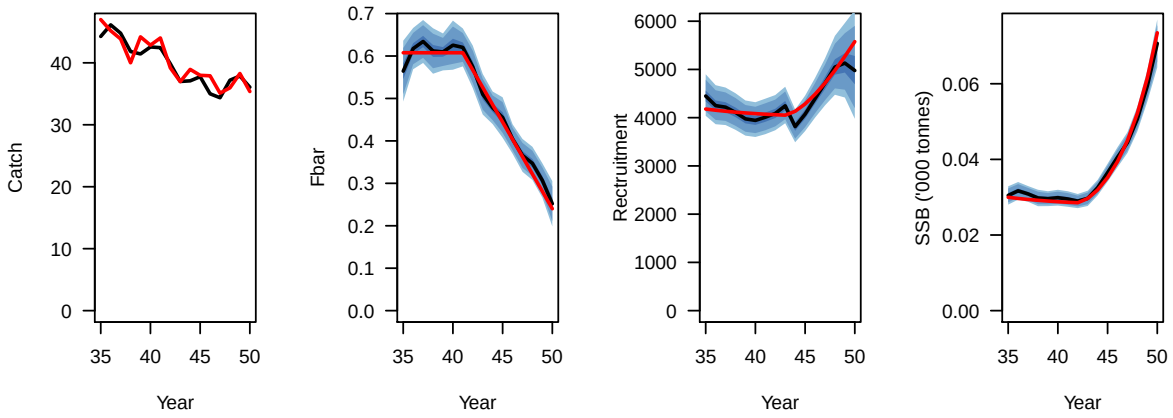


Figure 163: Model residuals. Colors represent ages

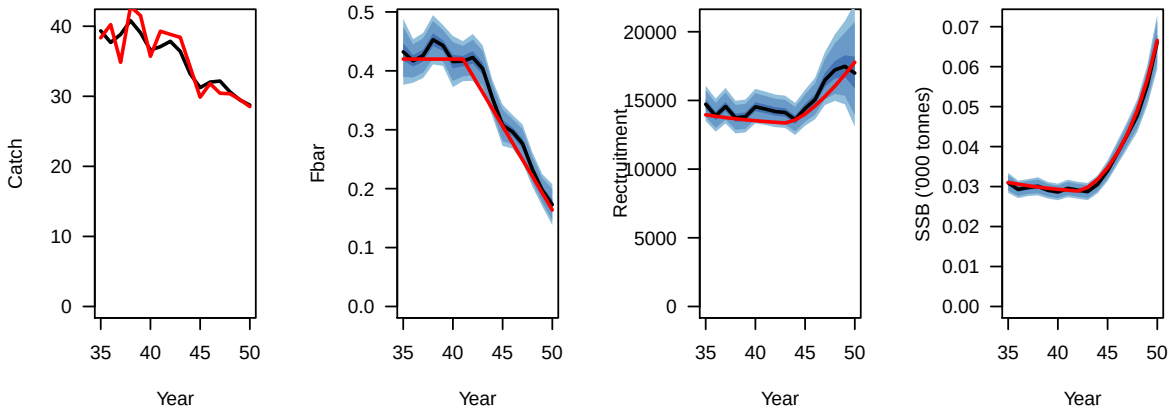


Figure 164: Model residuals. Colors represent ages

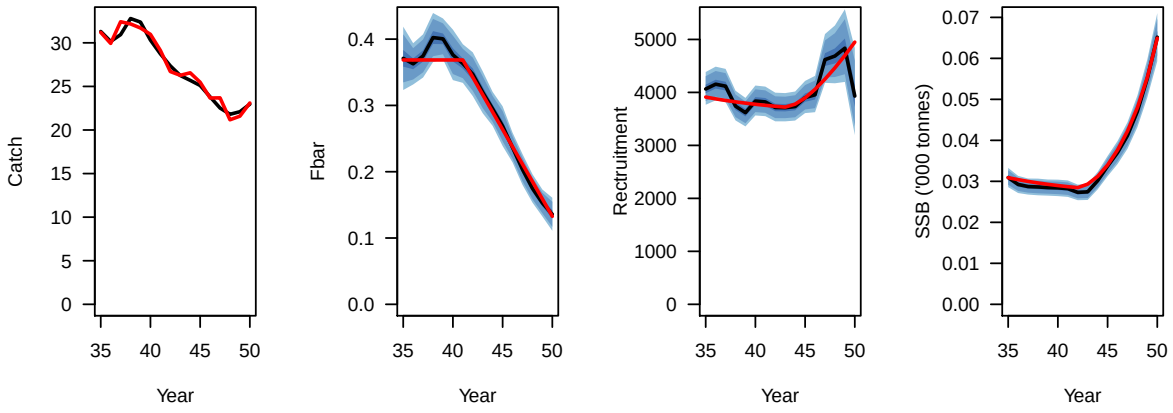
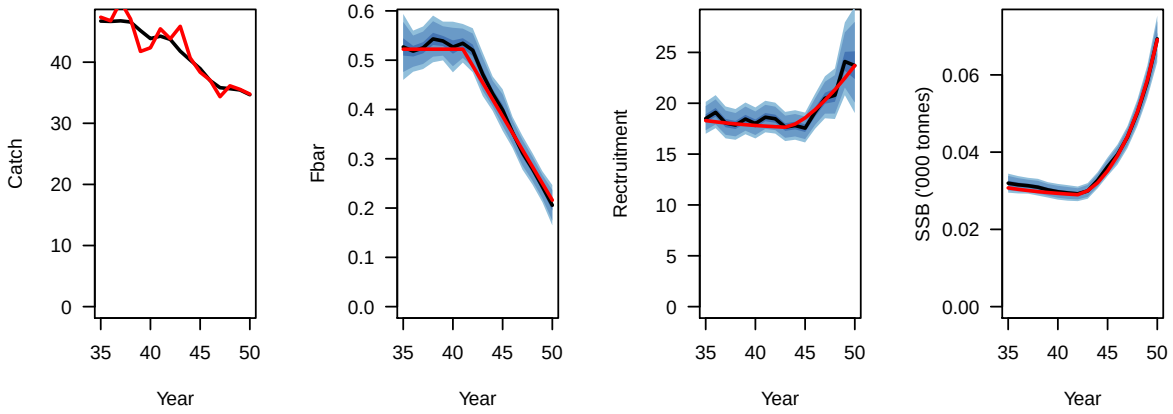


Figure 165: Model residuals. Colors represent ages



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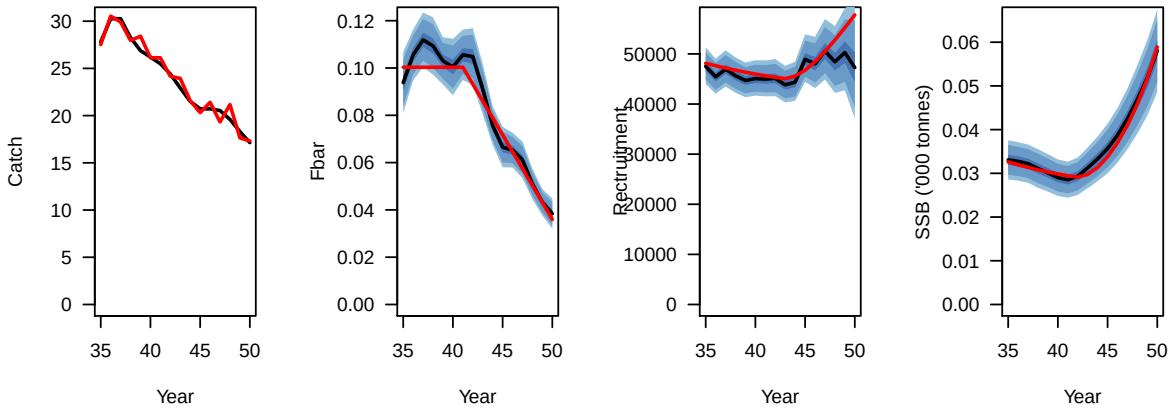


Figure 167: Model residuals. Colors represent ages

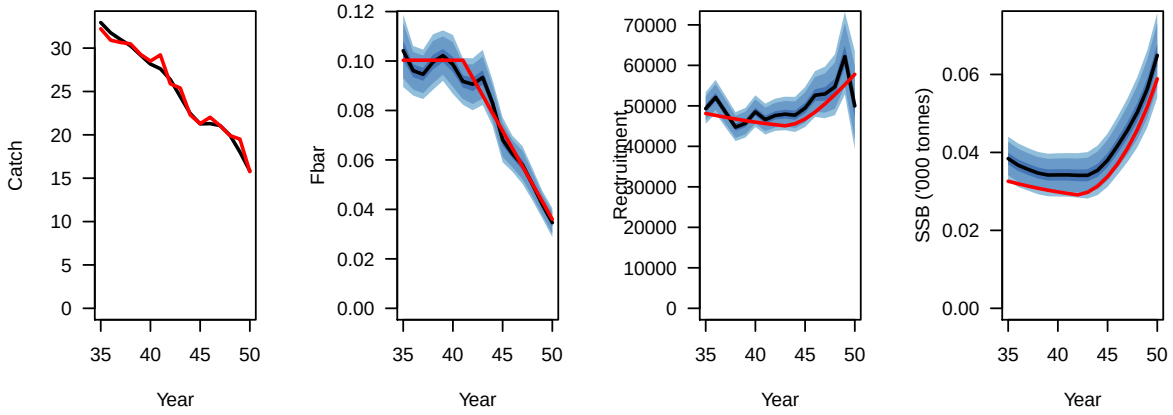
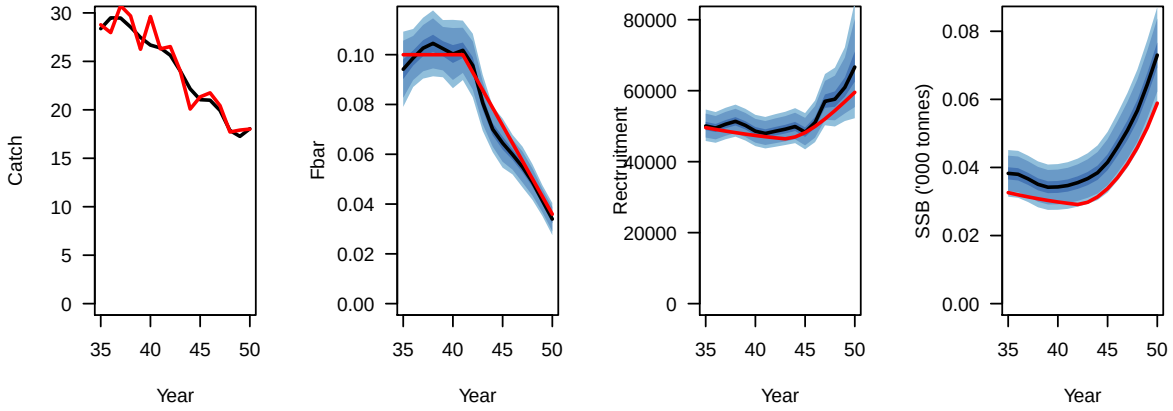


Figure 168: Model residuals. Colors represent ages



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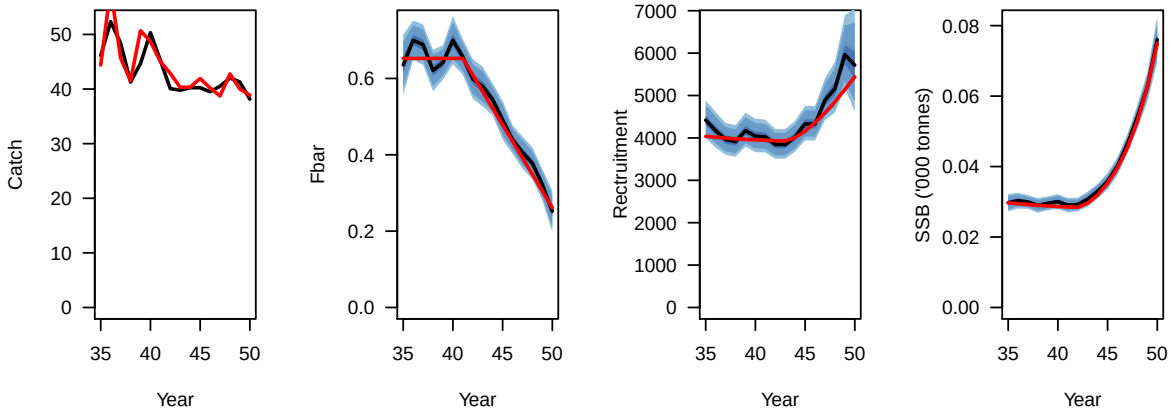
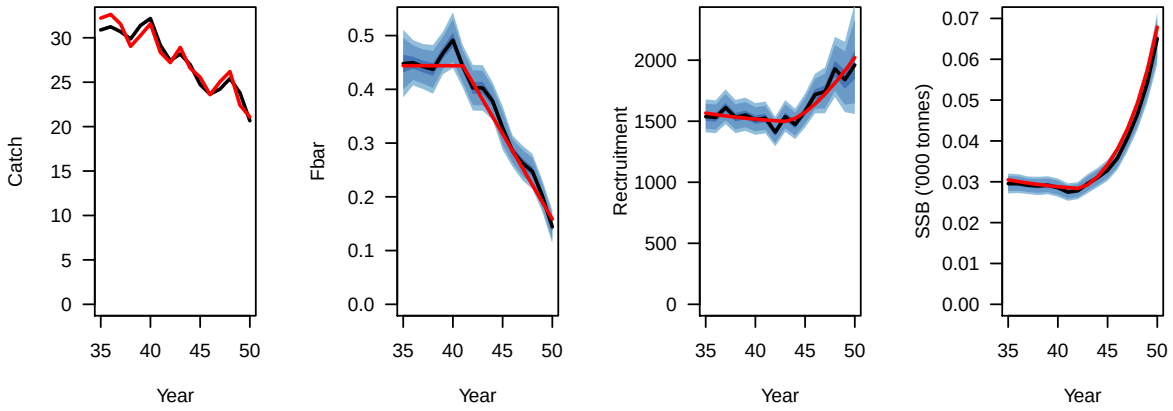


Figure 170: Model residuals. Colors represent ages



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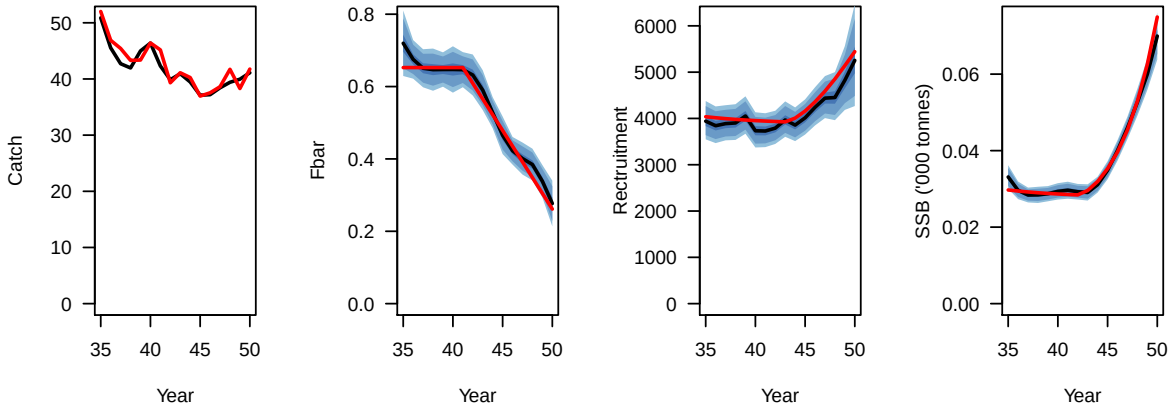

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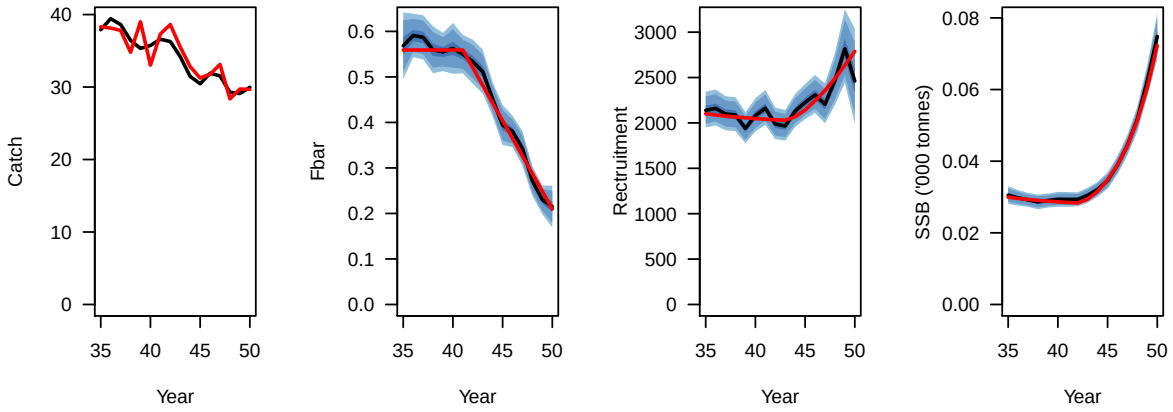

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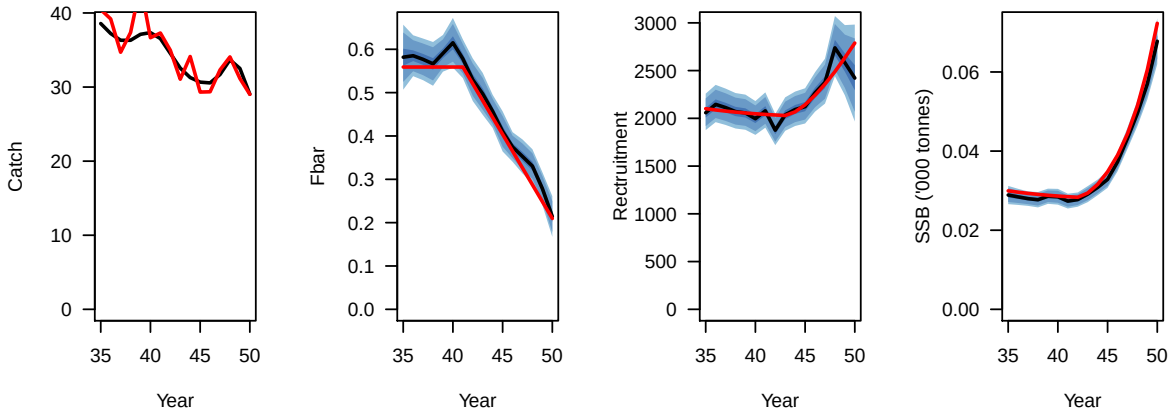

Figure 174: Model residuals. Colors represent ages

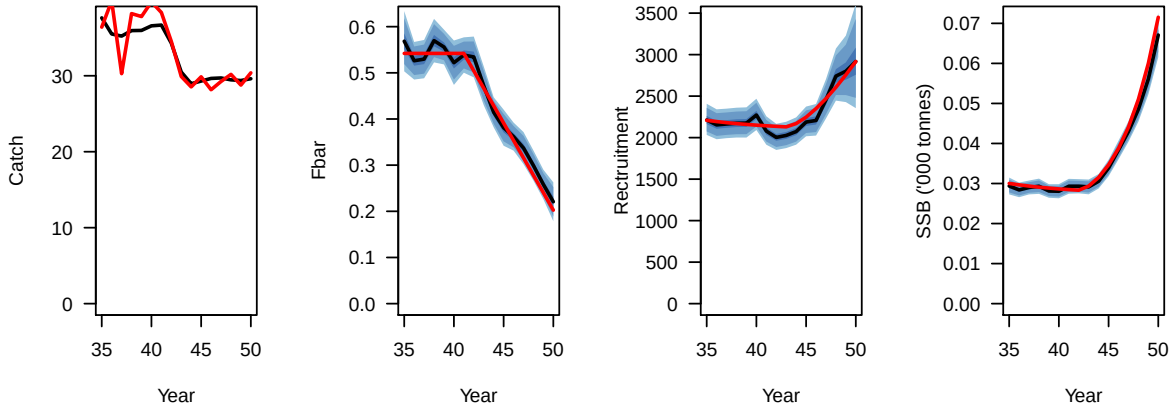

Figure 175: Model residuals. Colors represent ages

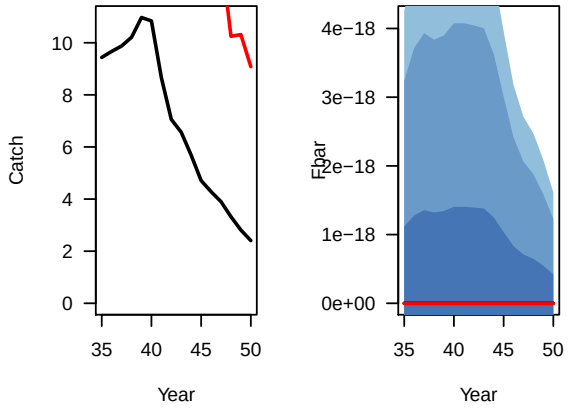

Figure 176: Model residuals. Colors represent ages

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## Error:  need finite 'ylim' values
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Full developing-stable-recovery

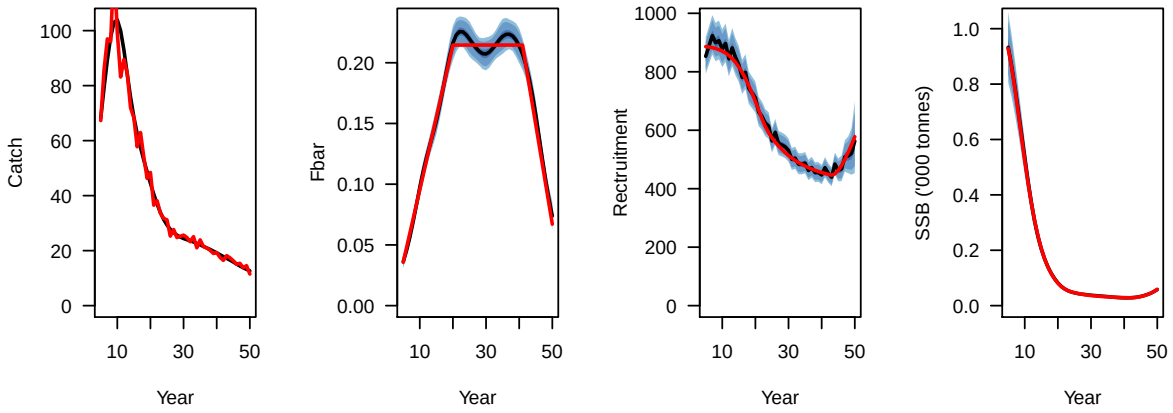


Figure 177: Model residuals. Colors represent ages

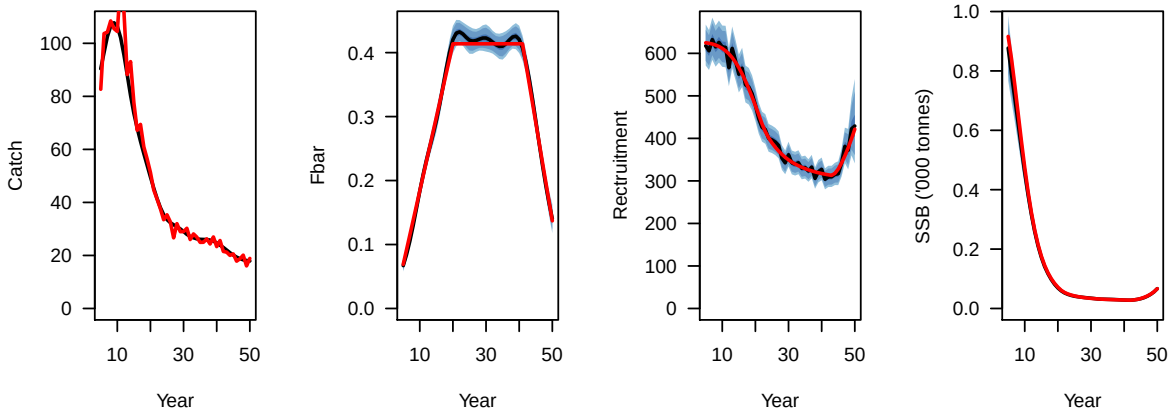


Figure 178: Model residuals. Colors represent ages

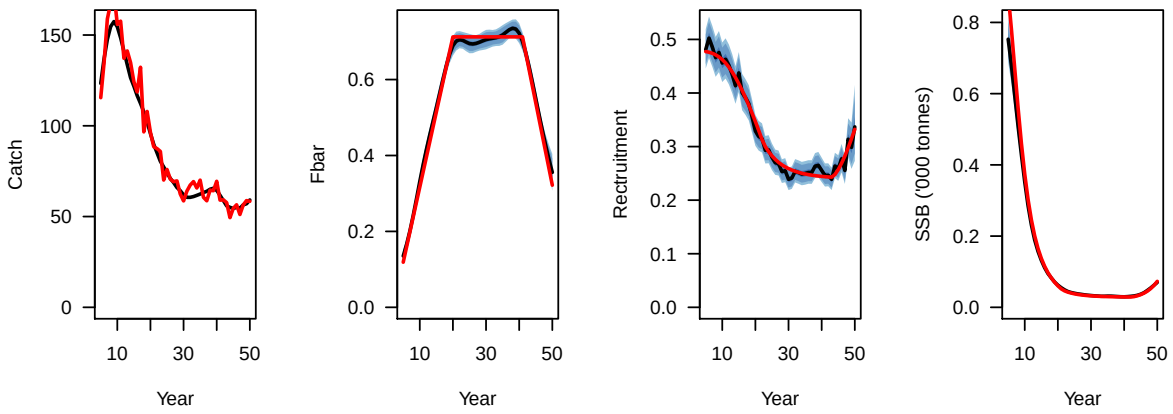


Figure 179: Model residuals. Colors represent ages

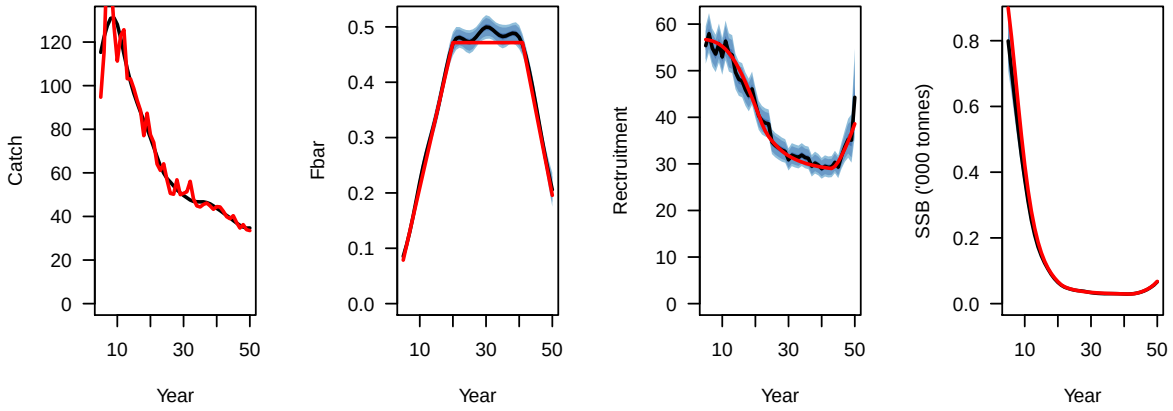


Figure 180: Model residuals. Colors represent ages

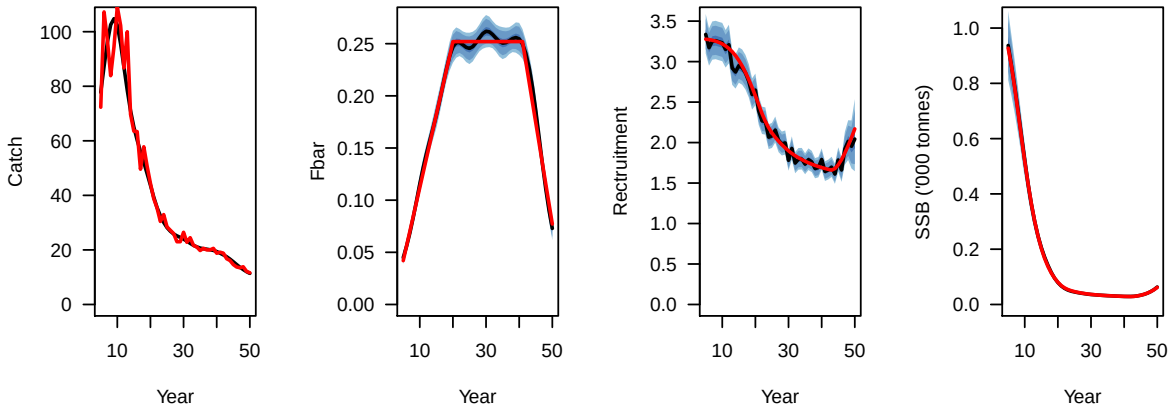


Figure 181: Model residuals. Colors represent ages

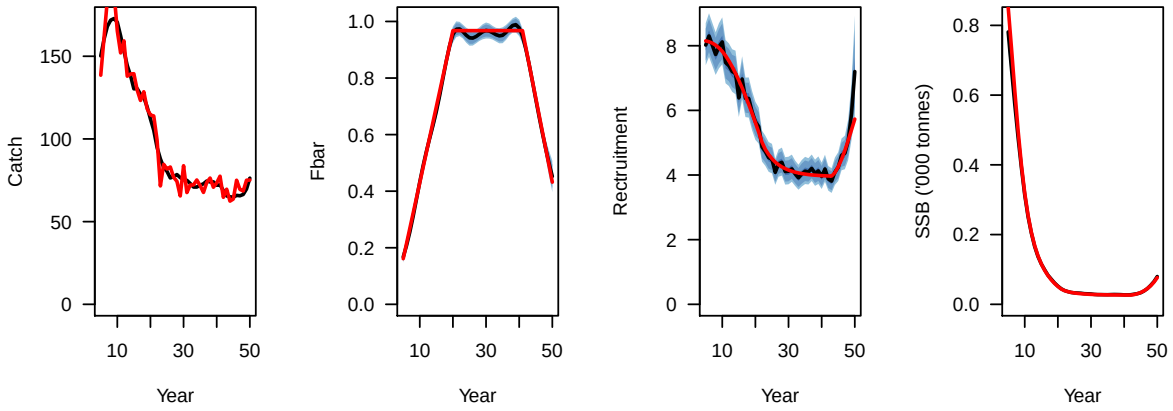


Figure 182: Model residuals. Colors represent ages

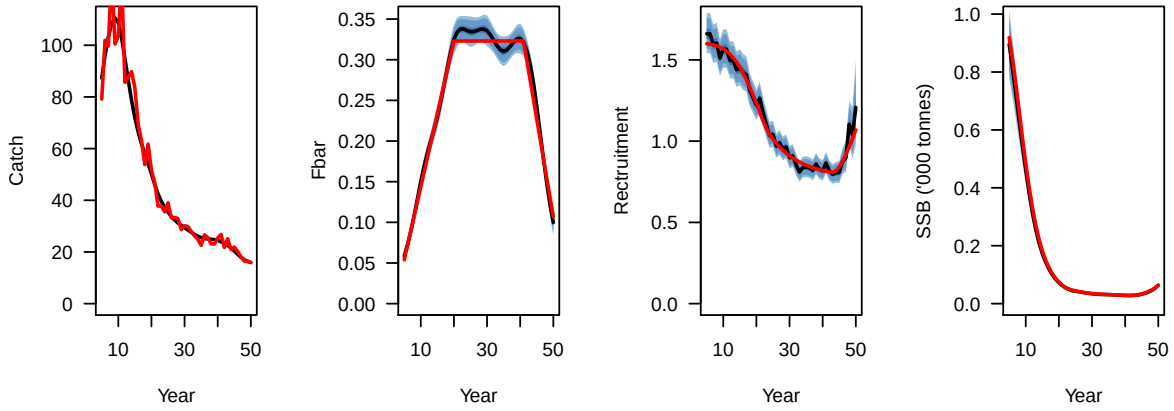


Figure 183: Model residuals. Colors represent ages

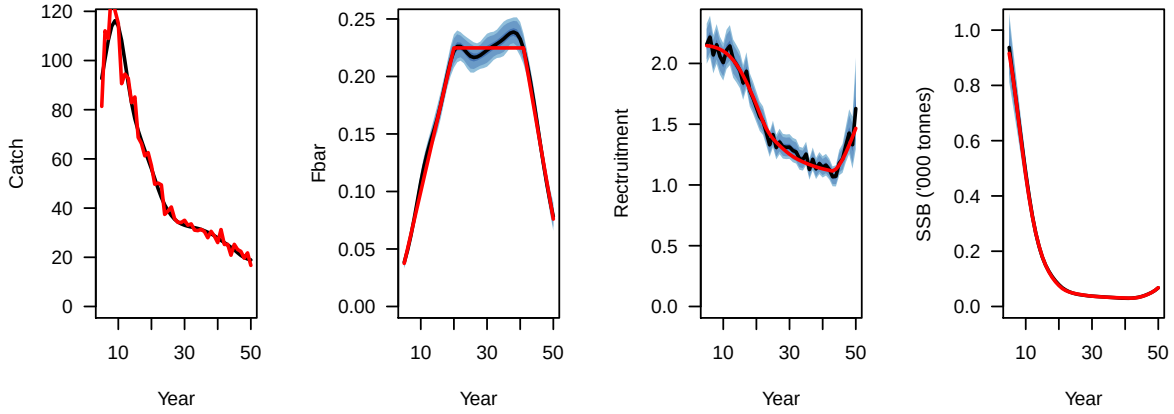


Figure 184: Model residuals. Colors represent ages

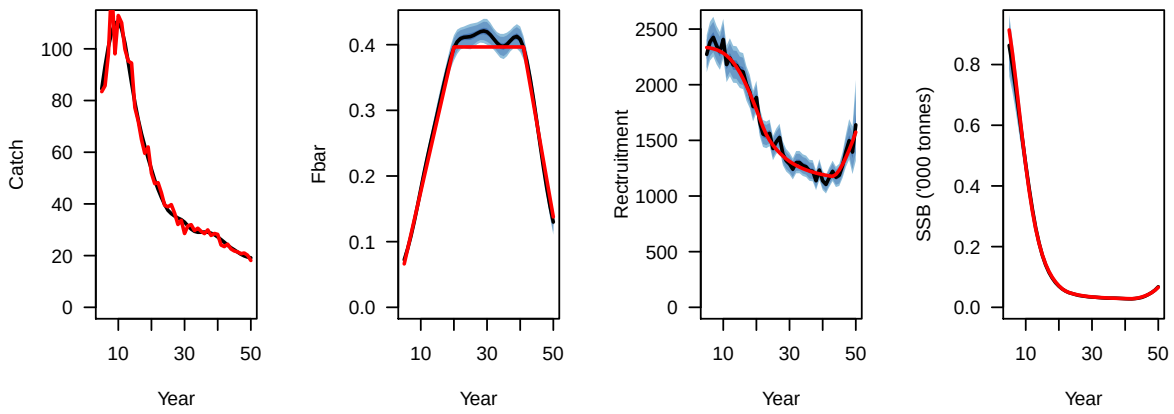


Figure 185: Model residuals. Colors represent ages

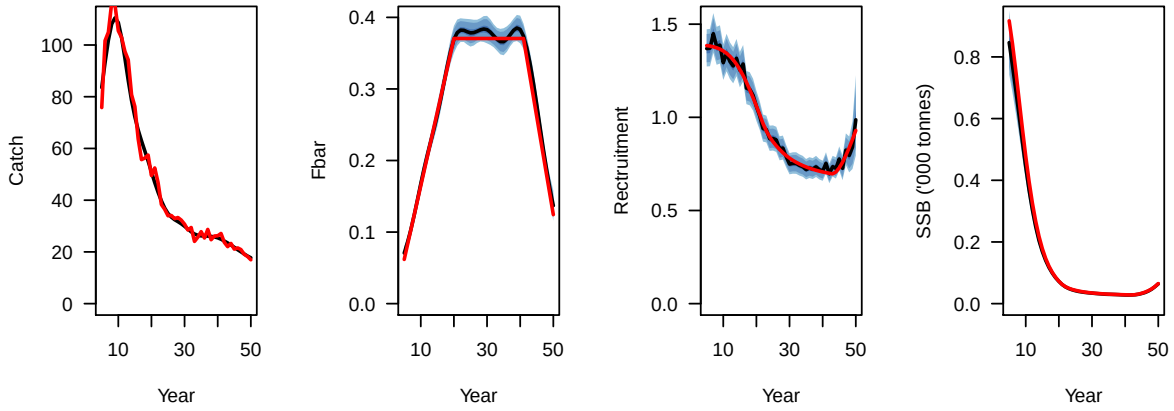


Figure 186: Model residuals. Colors represent ages

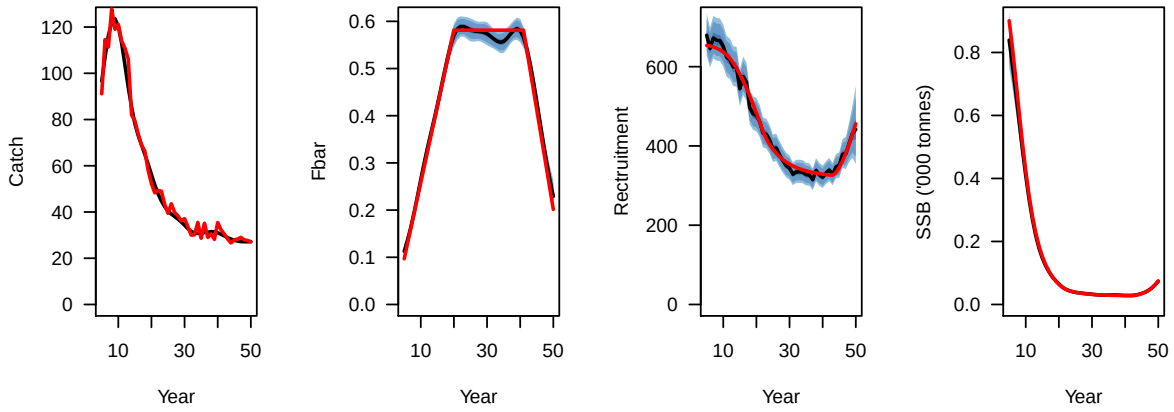


Figure 187: Model residuals. Colors represent ages

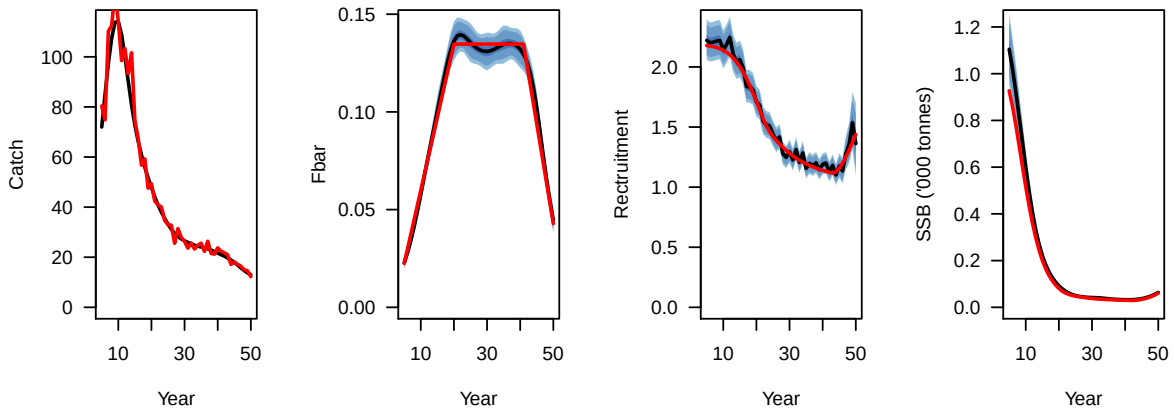


Figure 188: Model residuals. Colors represent ages

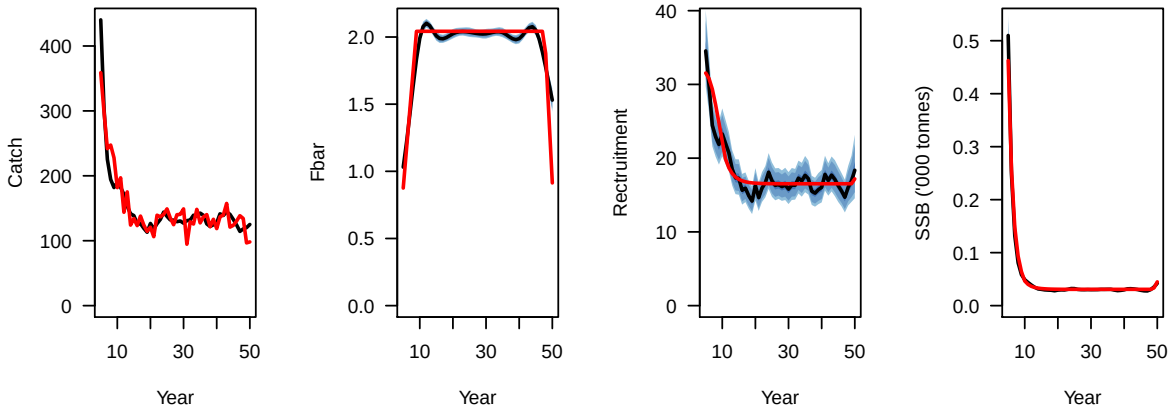


Figure 189: Model residuals. Colors represent ages

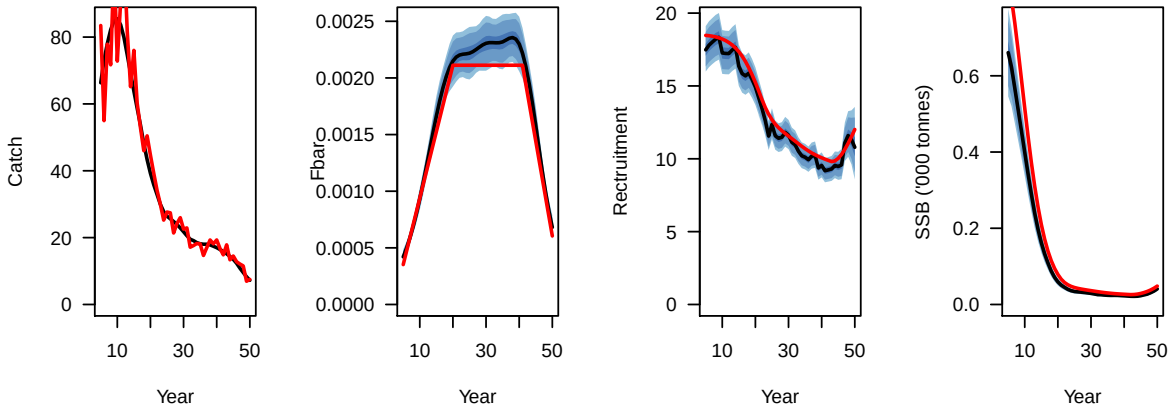


Figure 190: Model residuals. Colors represent ages

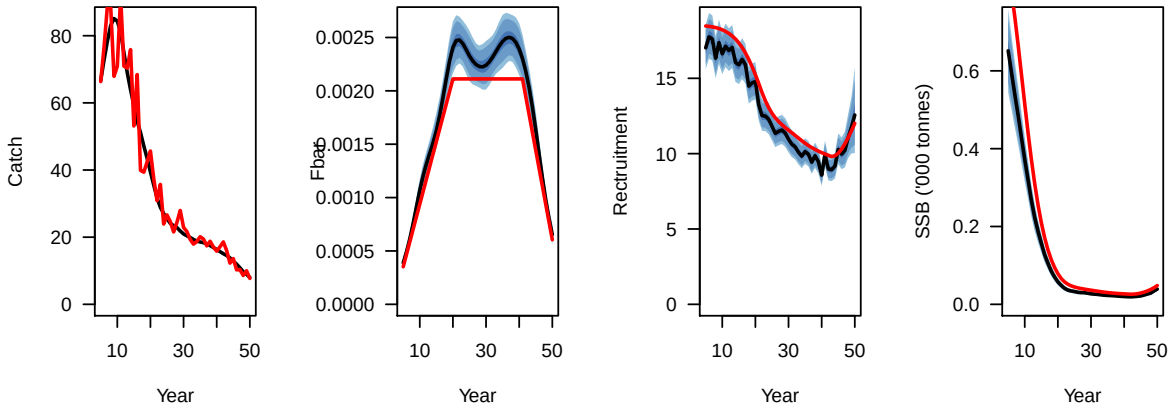


Figure 191: Model residuals. Colors represent ages

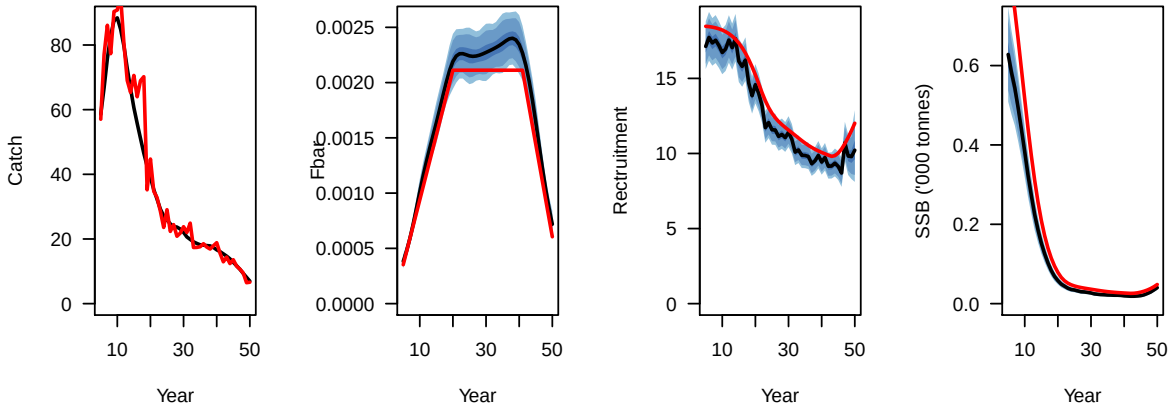


Figure 192: Model residuals. Colors represent ages

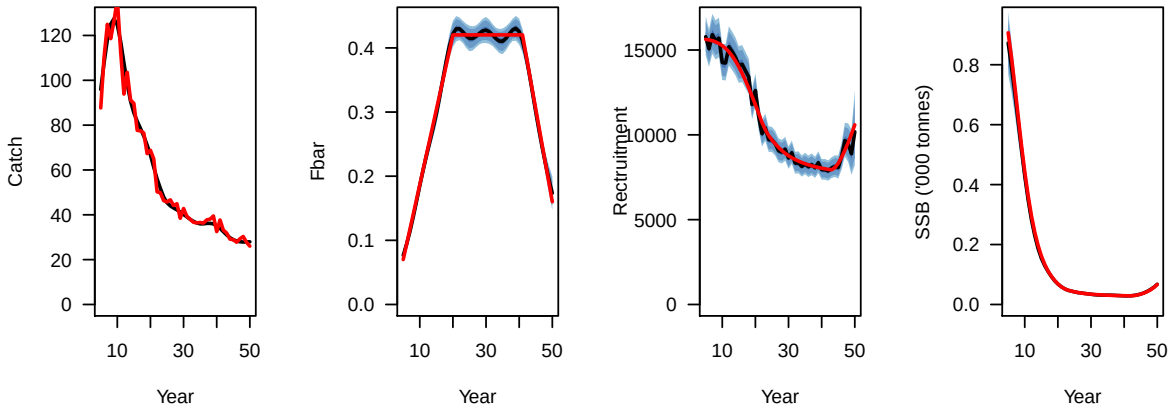
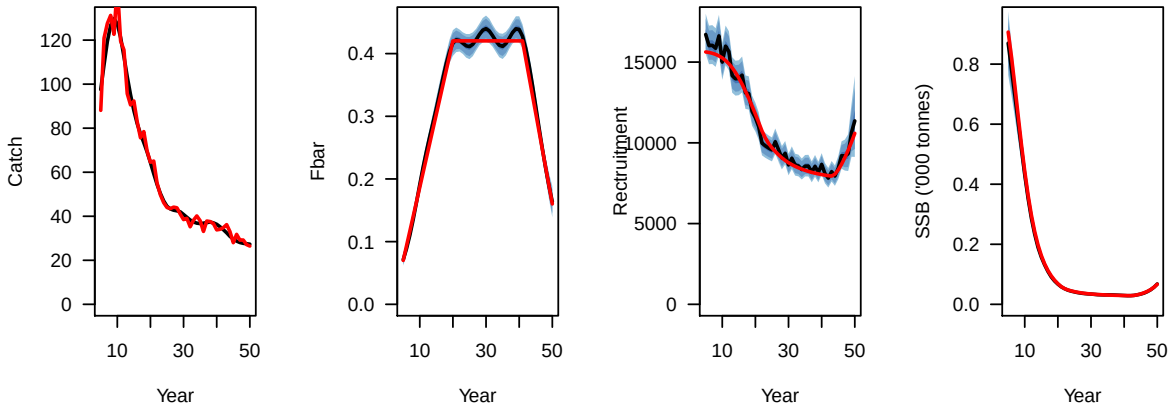


Figure 193: Model residuals. Colors represent ages



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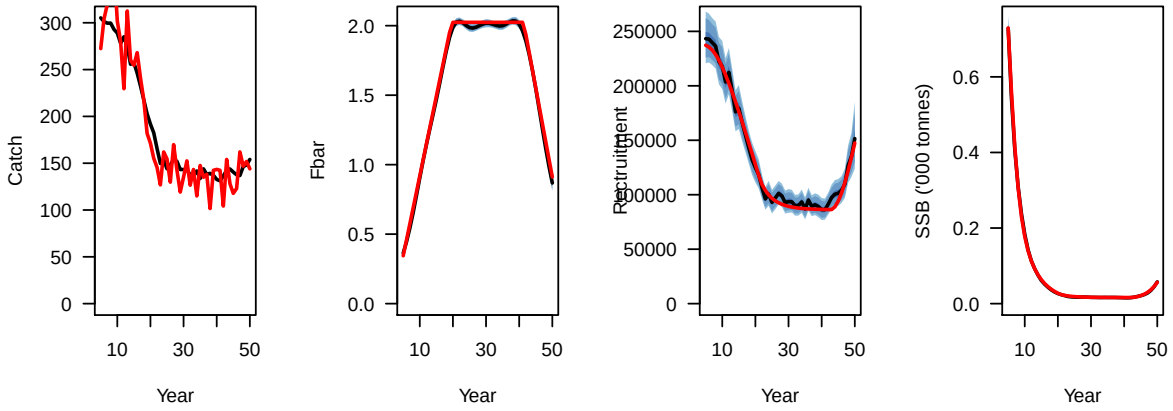

Figure 195: Model residuals. Colors represent ages

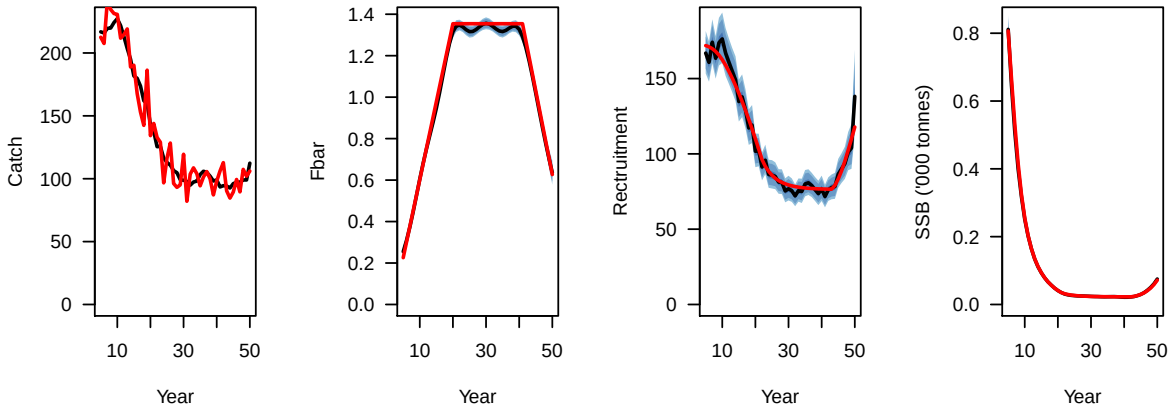

Figure 196: Model residuals. Colors represent ages

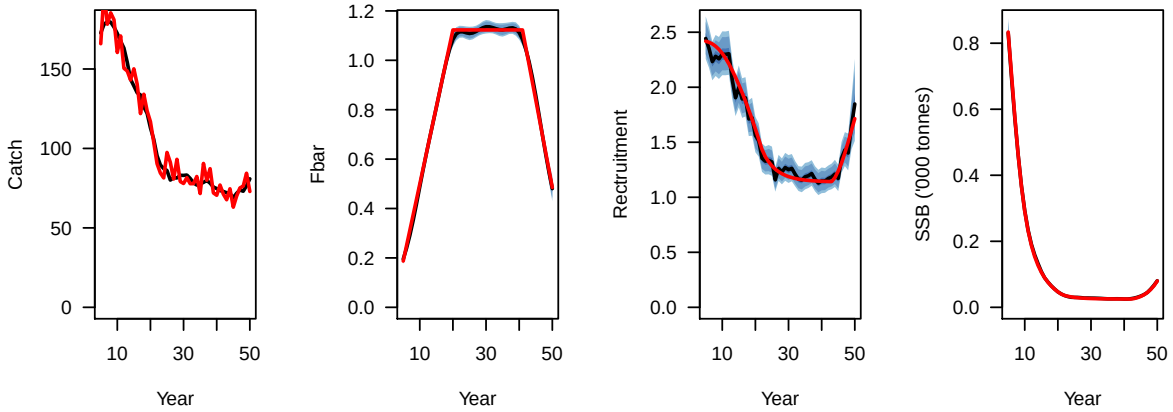

Figure 197: Model residuals. Colors represent ages

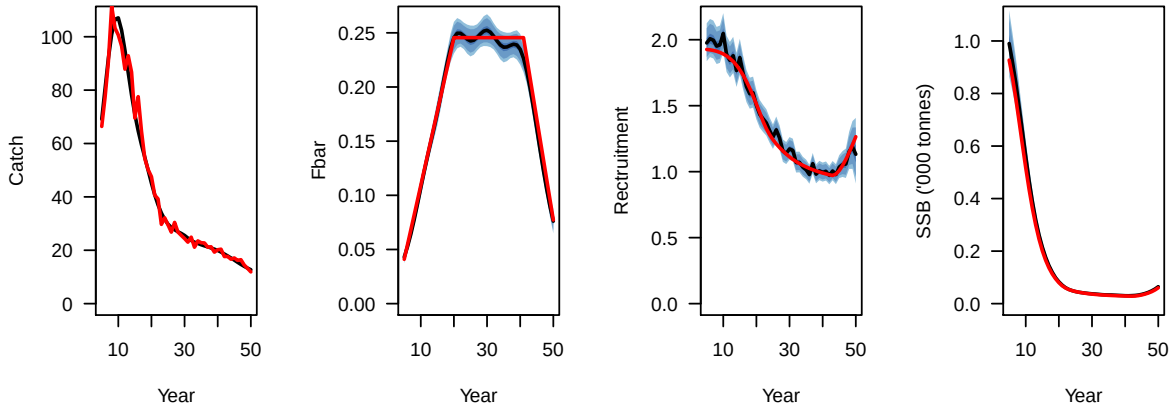

Figure 198: Model residuals. Colors represent ages

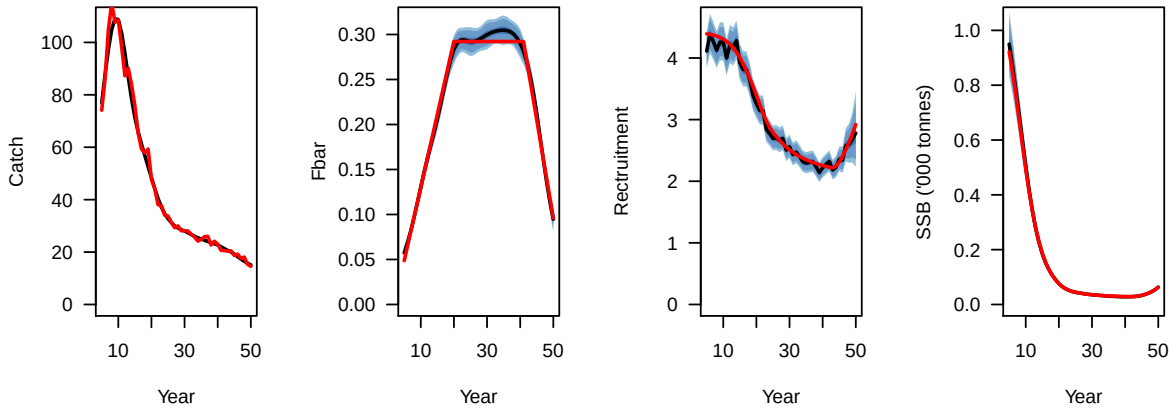

Figure 199: Model residuals. Colors represent ages

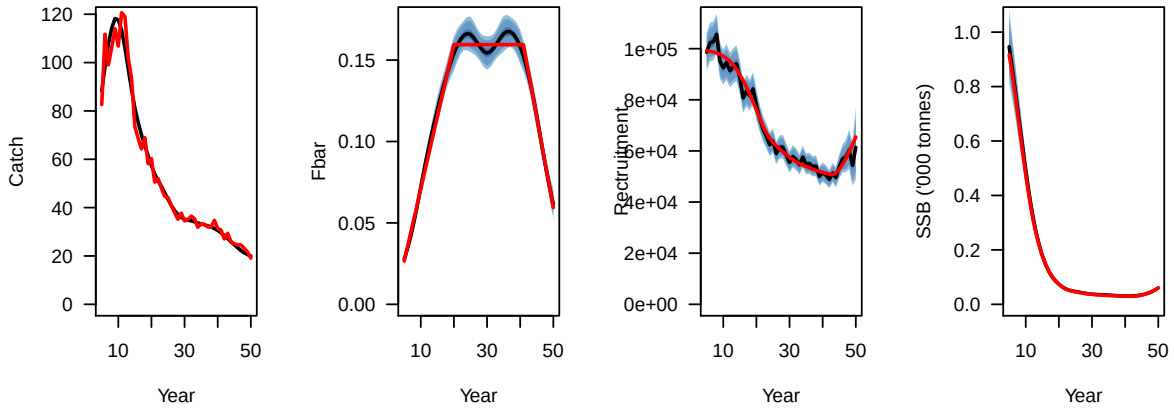

Figure 200: Model residuals. Colors represent ages

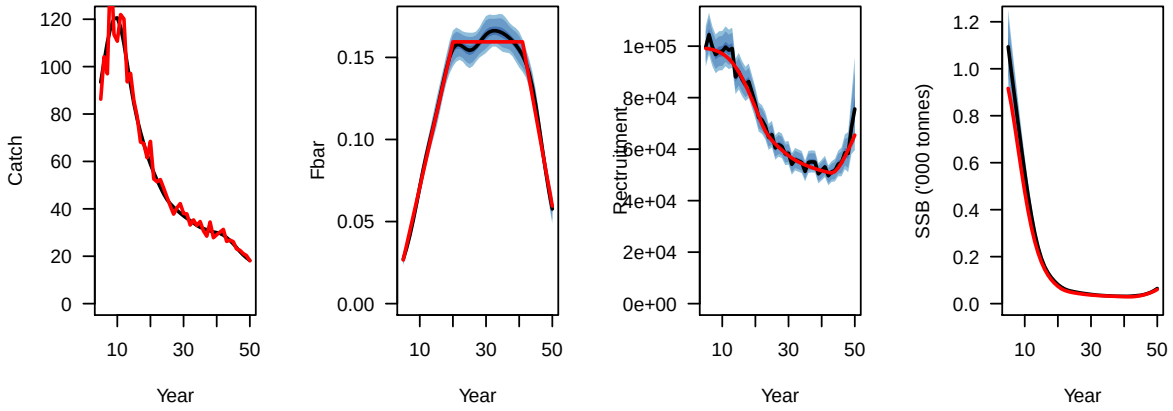

Figure 201: Model residuals. Colors represent ages

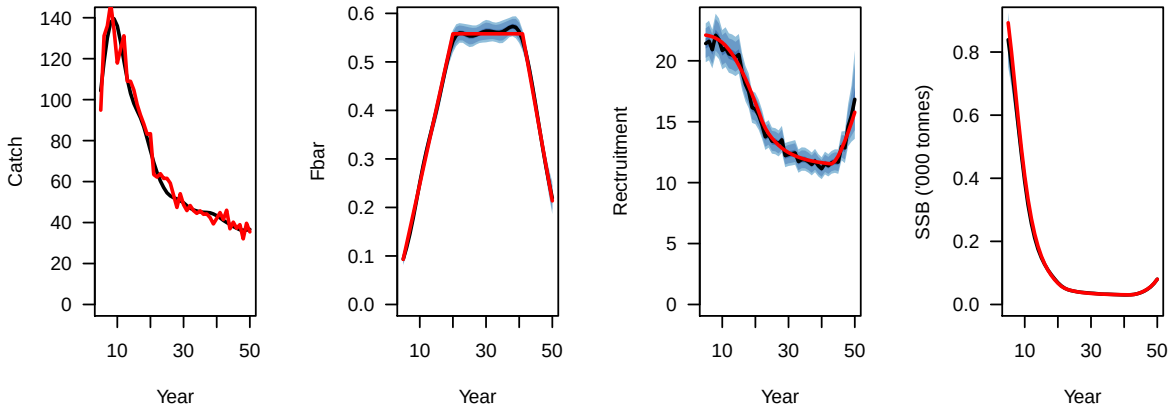

Figure 202: Model residuals. Colors represent ages

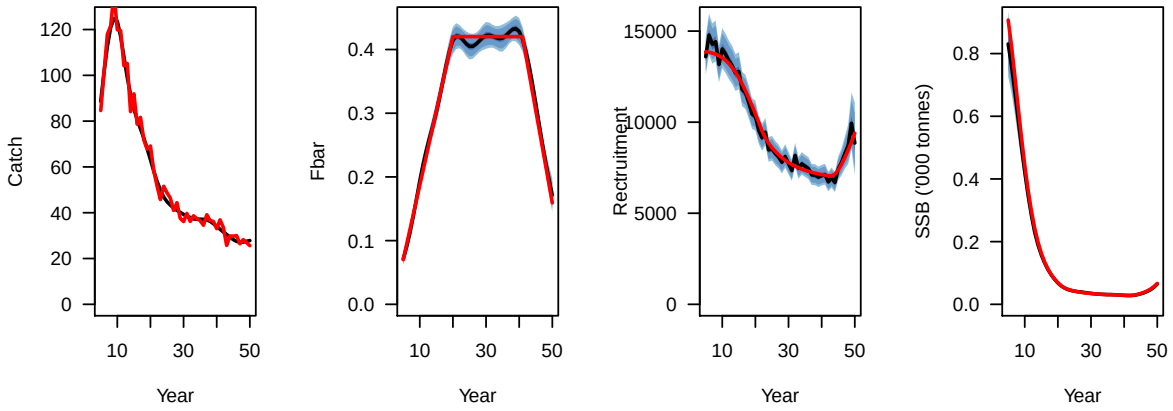

Figure 203: Model residuals. Colors represent ages

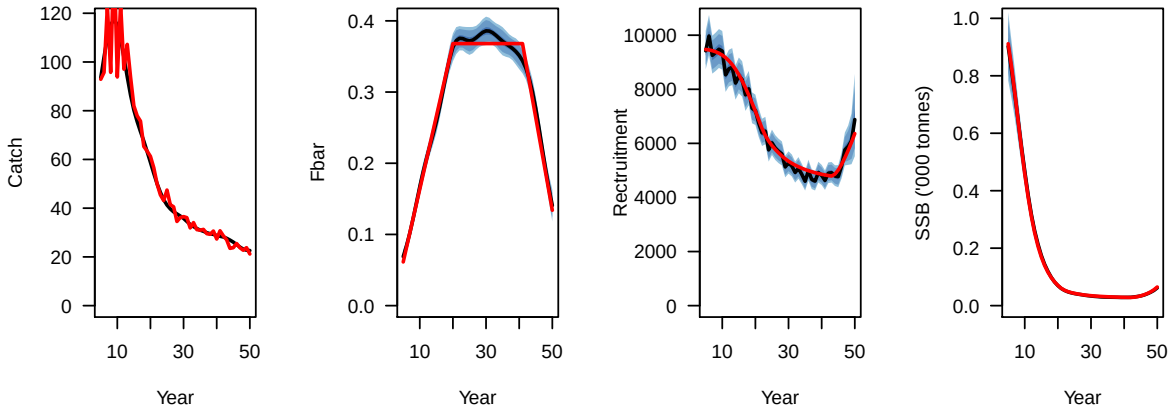

Figure 204: Model residuals. Colors represent ages

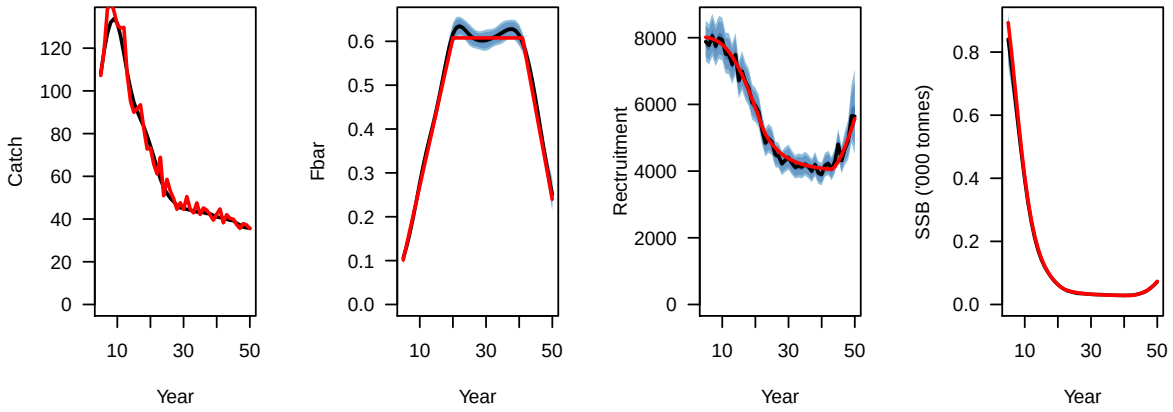

Figure 205: Model residuals. Colors represent ages

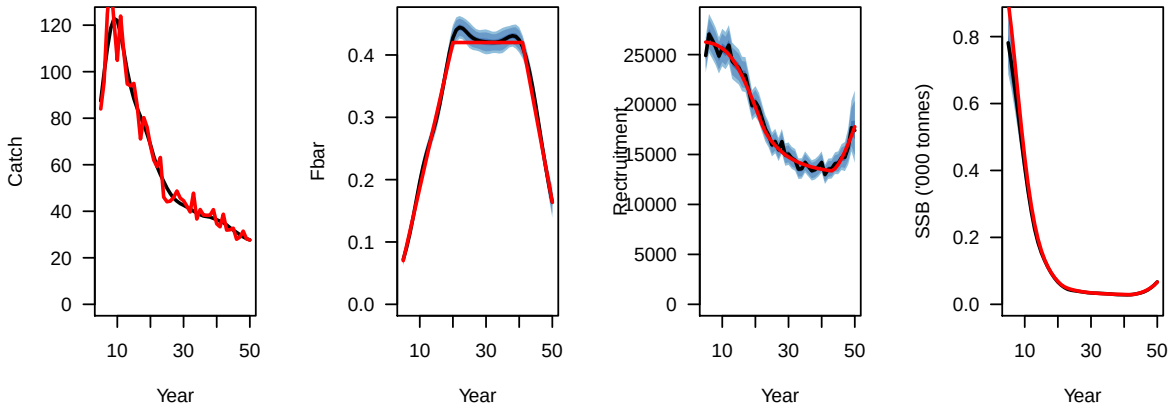

Figure 206: Model residuals. Colors represent ages

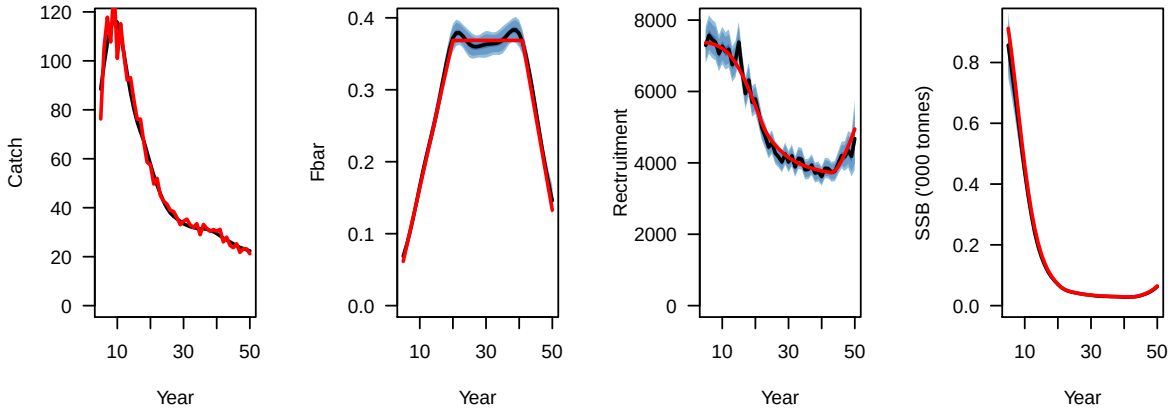

Figure 207: Model residuals. Colors represent ages

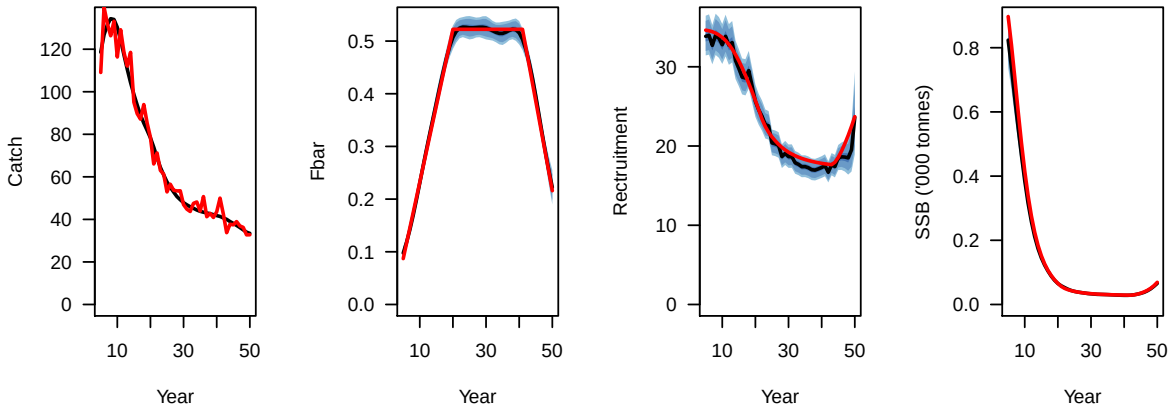

Figure 208: Model residuals. Colors represent ages

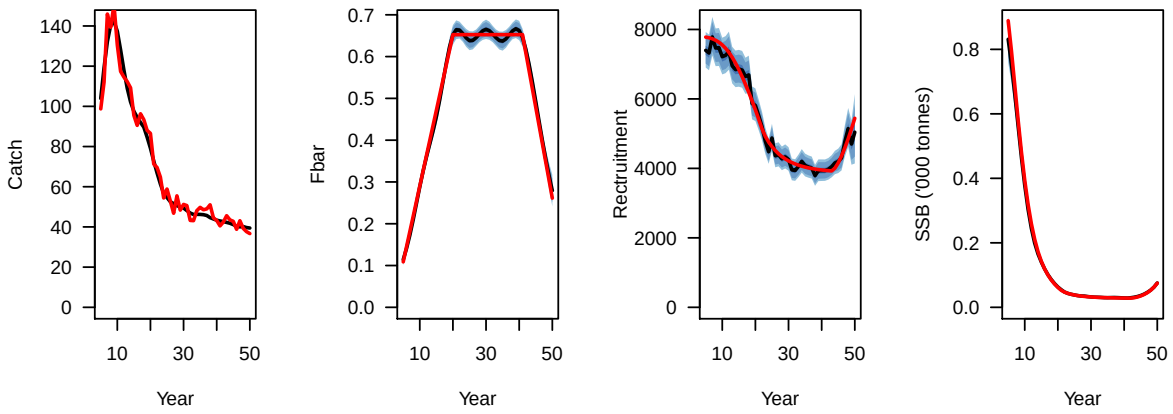

Figure 209: Model residuals. Colors represent ages

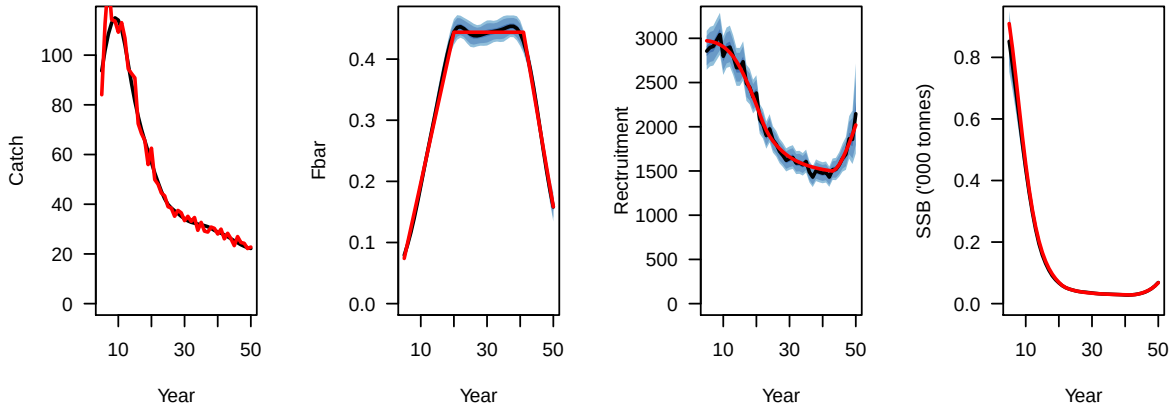

Figure 210: Model residuals. Colors represent ages

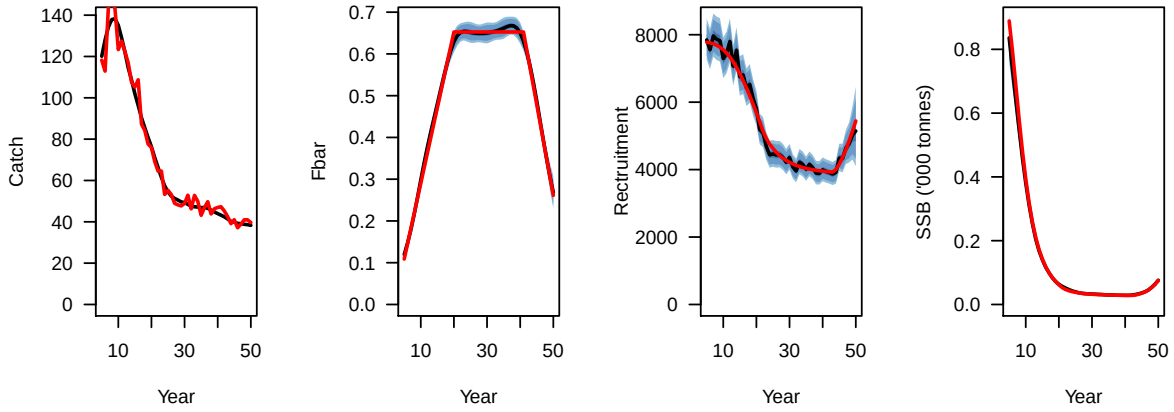

Figure 211: Model residuals. Colors represent ages

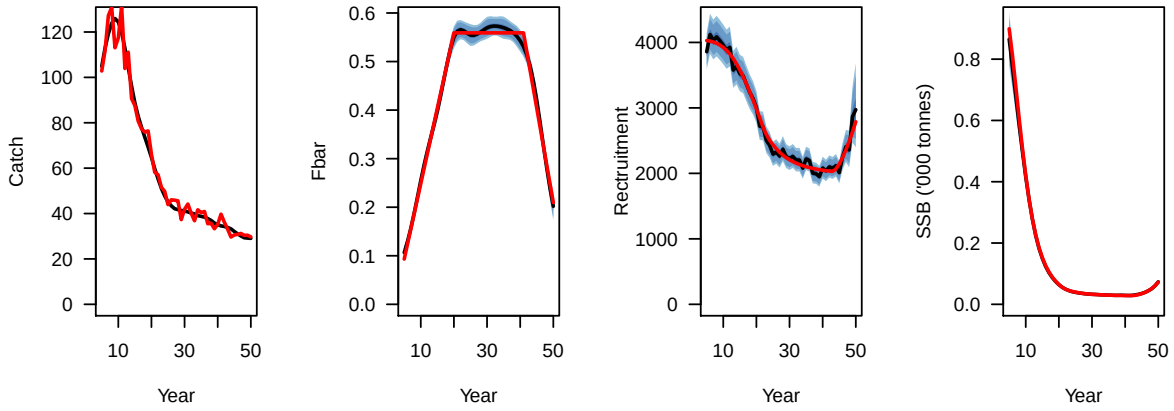

Figure 212: Model residuals. Colors represent ages

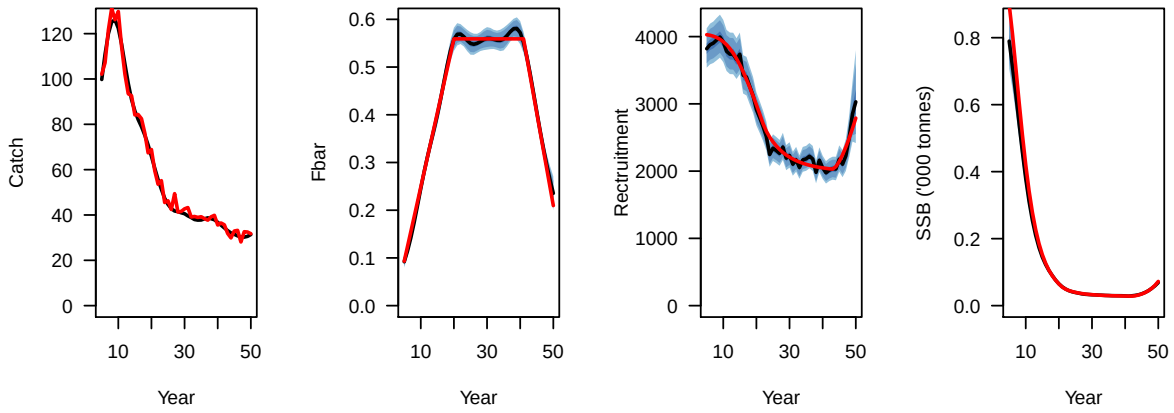

Figure 213: Model residuals. Colors represent ages

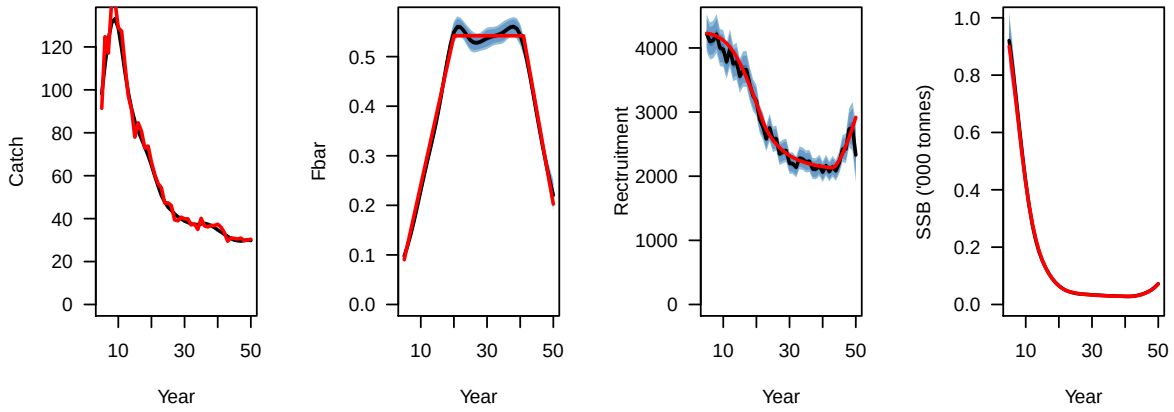

Figure 214: Model residuals. Colors represent ages

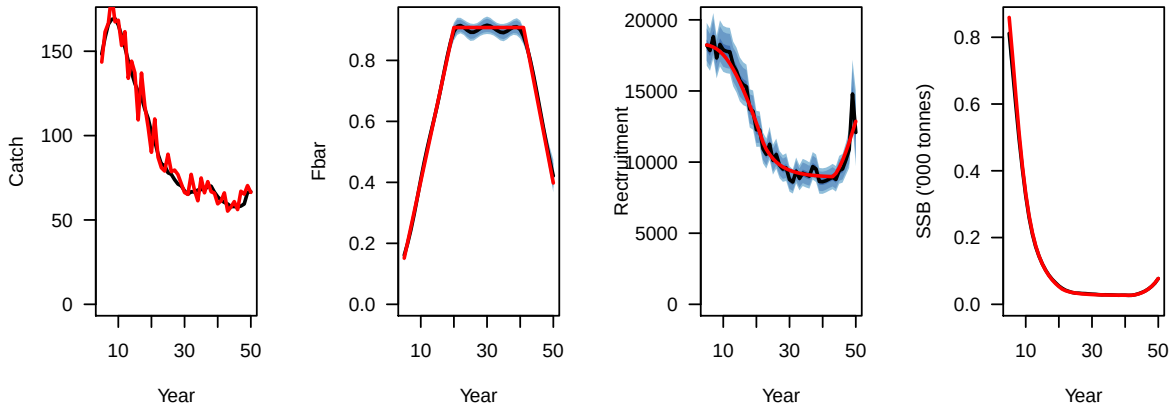

Figure 215: Model residuals. Colors represent ages

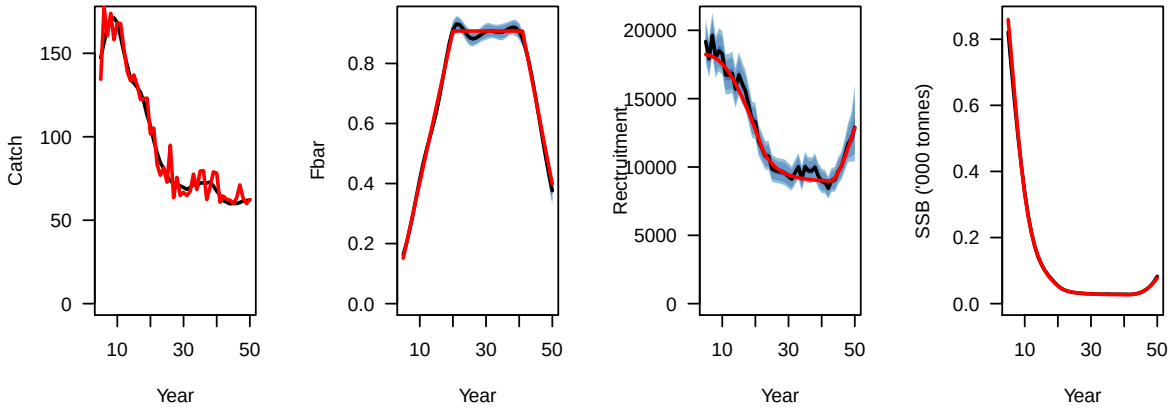

Figure 216: Model residuals. Colors represent ages

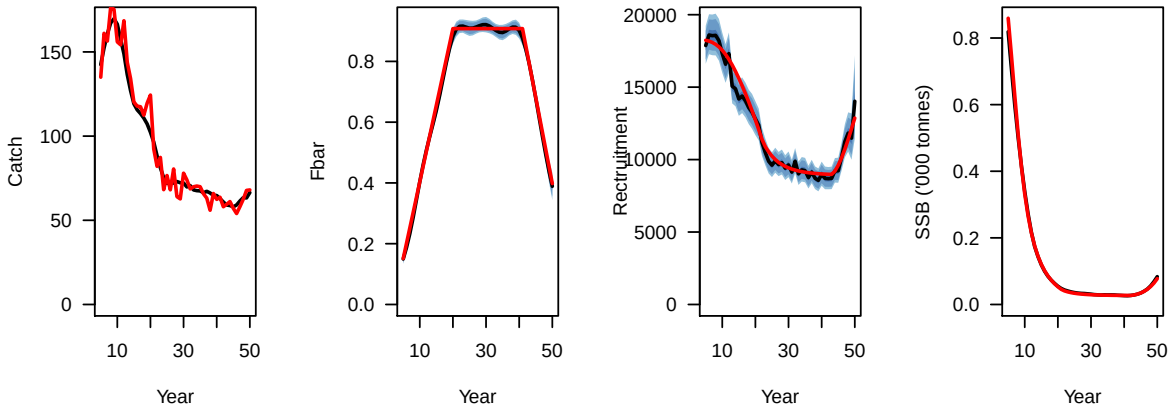

Figure 217: Model residuals. Colors represent ages

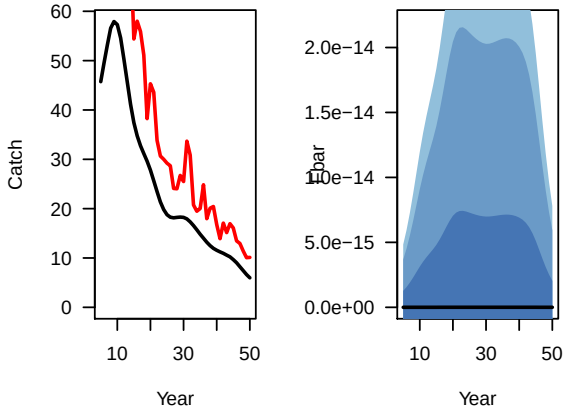

Figure 218: Model residuals. Colors represent ages

```
## Error:  need finite 'ylim' values
```

Appendix

R Session Information

```
sessionInfo()

## R version 2.15.2 (2012-10-26)
## Platform: x86_64-pc-linux-gnu (64-bit)
##
## locale:
##  [1] LC_CTYPE=en_US.UTF-8       LC_NUMERIC=C
##  [3] LC_TIME=en_GB.UTF-8        LC_COLLATE=en_US.UTF-8
##  [5] LC_MONETARY=en_GB.UTF-8    LC_MESSAGES=en_US.UTF-8
##  [7] LC_PAPER=C                 LC_NAME=C
##  [9] LC_ADDRESS=C               LC_TELEPHONE=C
## [11] LC_MEASUREMENT=en_GB.UTF-8 LC_IDENTIFICATION=C
##
## attached base packages:
## [1] splines   grid      datasets  utils     stats     graphics  grDevices
## [8] methods   base
##
## other attached packages:
##  [1] ggplotFL_0.1     ggplot2_0.9.2.1  multicore_0.1-7  Hmisc_3.10-1
##  [5] survival_2.36-14 plyr_1.7.1       FLa4av2_0.1.1    mgcv_1.7-22
##  [9] Matrix_1.0-10    FLAssess_2.5.0   FLCore_2.5.0     knitr_0.8
## [13] lattice_0.20-10  MASS_7.3-22      vimcom_0.9-2     setwidth_1.0-0
## [17] colorout_0.9-9
##
## loaded via a namespace (and not attached):
##  [1] cluster_1.14.3     colorspace_1.2-0   dichromat_1.2-4
##  [4] digest_0.5.2       evaluate_0.4.2     formatR_0.6
##  [7] gtable_0.1.1       labeling_0.1       memoise_0.1
## [10] munsell_0.4        nlme_3.1-105       proto_0.3-9.2
## [13] RColorBrewer_1.0-5 reshape2_1.2.1     scales_0.2.2
## [16] stats4_2.15.2      stringr_0.6.1      tools_2.15.2
```

European Commission
EUR 25661 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen

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Abstract

The a4a initiative aims to provide timely and cost effective advice for the circa. 250 fish stocks that, through the EU Data Collection Framework, will have at least 10 years of data by the year 2020. Current processes for assessing the state of and managing fish stocks are intensive processes, each stock requiring the attention of one or more stock assessment scientist to produce preliminary catch advice, which is subsequently reviewed by one or two committees before the final catch advice is published. Ingrained in the development of these processes has been the development of more and more complex stock assessment models which typically require highly skilled personnel to set up and run.

The a4a initiative seeks to overcome these issues by developing a flexible, robust and easy to use stock assessment model, thus making stock assessment accessible to a wide range of scientists that do not have the high skilled quantitative background required to run very complex models. Forthcoming research will describe how to overcome the burden of producing catch advice for such a large number of stocks. This technical report presents a new stock assessment model along with a set of validatory tests developed under the a4a Initiative.

LB-NA-25661-EN-N

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

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